Historia de los cielos.

"Tél "Historia de los cielos" es el título de nuestro libro. De hecho, tenemos un una historia maravillosa para contar; ¿Y podríamos contarle adecuadamente que lo haría demostración de interés sin límites y de exquisita belleza. Conduce a la contemplación de grandes fenómenos en la naturaleza y grandes logros de Genio humano.

Enumeremos algunas de las preguntas que se plantearán de forma natural Alguien que busca aprender algo de esos cuerpos gloriosos que adornan nuestros cielos: ¿Qué es el Sol—qué tan caliente, qué tan grande y qué tan lejano? De dónde ¿Viene su calor? ¿Qué es la Luna? ¿Cómo son sus paisajes? ¿Cómo lo dices ¿Nuestro movimiento de satélite? ¿Cómo está relacionado con la Tierra? ¿Son los planetas ¿Globos como el que vivimos? ¿Qué tamaño tienen y qué distancia están equivocadas? ¿Qué sabemos de los satélites de Júpiter y de los anillos de Saturno? ¿Cómo se descubrió Urano? ¿Cuál fue el triunfo intelectual que ¿sacó a la luz el planeta Neptuno? Luego, en cuanto a los otros cuerpos de nuestro Sistema, ¿qué podemos decir de esos misteriosos objetos, los cometas? Can ¿Descubrimos las leyes de sus movimientos aparentemente caprichosos? ¿Lo sabemos? Nada de su naturaleza y de las maravillosas colas con las que están ¿a menudo decorado? ¿Qué se puede contar sobre las estrellas fugaces que así ¿a menudo se lanzan a nuestra atmósfera y perecen en una estela de esplendor? ¿Qué es la naturaleza de esas constelaciones de estrellas brillantes que han sido reconocido desde toda la antigüedad, y de la multitud de estrellas menores que ¿Nuestros telescopios revelan? ¿Puede ser cierto que estos incontables orbes son Soles realmente majestuosos, hundidos a un nivel espantoso[Pág. 2] profundidad en el abismo de ¿Espacio insondable? ¿Qué tenemos que contar sobre las diferentes variedades de estrellas—de estrellas de colores, de estrellas variables, de estrellas dobles, de múltiples estrellas, de estrellas que parecen moverse, y de estrellas que parecen en ¿Descansar? ¿Y qué hay de esos gloriosos objetos, los grandes cúmulos estelares? ¿Y qué de ¿la Vía Láctea? Y, por último, ¿qué podemos aprender sobre las maravillosas nebulosas? que nuestros telescopios revelan, a una distancia incalculable? Así son algunas de las preguntas que surgen cuando reflexionamos sobre los misterios de los cielos.

La historia de la astronomía es, en un sentido, demasiado parecida a la de muchos otros historias. La parte más temprana está completamente y desesperadamente perdida. Se habían estudiado las estrellas, y algunos grandes descubrimientos astronómicos se ha hecho, siglas incontables antes de aquellos a los que nuestra historia más antigua Los registros se extienden. Por ejemplo, la observación del movimiento aparente de el sol, y la discriminación entre los planetas y las estrellas fijas, ambos deben clasificarse entre los descubrimientos de la época prehistórica. Ni tampoco Cabe decir que estos logros se relacionaban con asuntos de una obvia carácter. La astronomía antigua puede parecer muy elemental para quienes la Hoy en día, que desde la infancia han estado familiarizados con las grandes verdades de la naturaleza, pero, en la infancia de la ciencia, de los hombres que crearon tales Los descubrimientos, como hemos mencionado, debieron ser filósofos sabios.

De todos los fenómenos astronómicos, el primero y el más evidente es que del amanecer y el atardecer del sol. Podemos suponer que al amanecer de inteligencia humana, estos sucesos diarios formarían uno de los Primero problemas para captar la atención de quienes pensaban por encima de las ansiedades animales de la existencia cotidiana. Se pone un sol y desaparece en el oeste. A la mañana siguiente, un sol sale por el este, se mueve por los cielos, y también desaparece en el oeste; Lo mismo Las apariciones se repiten todos los días. Para nosotros es obvio que el sol, que aparece cada día, es el mismo sol; pero esto no parecería razonable uno que pensaba que sus sentidos le mostraban que la tierra era una llanura plana de extensión indefinida, y la que rodea las regiones habitadas en todos los lados extendidos, a vastas distancias, ya sea desérticos o océanos sin huellas. ¿Cómo podía ese mismo sol, que se sumergió en el océano de una forma fabulosa distancia en el oeste,[Pág. 3] reaparecer a la mañana siguiente en un lugar igualmente grande ¿Distancia en el este? La antigua mitología afirmaba que después del sol sumergidos en el océano occidental al atardecer (los ibéricos y otros antiguos naciones, en realidad imaginaban que podían oír el siseo de la cuando la esfera luminosa fue sumergida en ella), fue tomada por Vulcano y colocado en una copa dorada. Esta extraña nave con su Asombrosas cargas navegaban el océano por un rumbo norteño, para que Llega de nuevo al este a tiempo para el amanecer de la mañana siguiente. Entre Se creía que los primeros físicos antiguos eran que, de alguna manera, El sol se transmitía por la noche a través de las regiones del norte, y esa oscuridad se debía a las altas montañas, que protegían los rayos solares durante el viaje.

Con el paso del tiempo se consideró más racional suponer que la Sun siguió su curso bajo la tierra sólida durante el recorrido de la noche. Además, los primeros astrónomos habían aprendido a reconocer las estrellas fijas. Se observó que, al igual que el sol, muchas de estas estrellas se levantaba y se ponía en consecuencia del movimiento diurno, mientras que la luna Obviamente seguía una ley similar. Los filósofos enseñaron así que el Diversos cuerpos celestes solían pasar realmente por debajo la tierra sólida.

Por el reconocimiento de que todo el contenido de los cielos cumplió Estos movimientos, un paso importante para comprender la constitución de el universo había sido decididamente tomado. Estaba claro que la tierra podía No ser un avión que se extiende a una distancia indefinidamente grande. También lo fue Es obvio que debe haber una profundidad finita en la tierra bajo nuestros pies. Más bien, se hizo seguro que, sea cual sea la forma de la tierra En todo caso, era algo desconectado de todos los demás cuerpos, y En posición sin soporte visible en el espacio. Cuando se produjo este descubrimiento por primera vez anunció que debía parecer una verdad muy sorprendente. Era tan difícil de comprender que la tierra sólida sobre la que nos apoyamos reposaba ¡Nada! ¿Qué evitaba que cayera? ¿Cómo podría mantenerse ¿sin apoyo tangible, como el legendario ataúd de Mahoma? Pero Por difícil que fuera recibir esta doctrina, pero es Verdad necesaria a su debido tiempo[Pág. 4] ordenó el asentimiento, y la ciencia de La astronomía comenzó a existir. Los cambios de estación y la recurrencia de la época de siembra y cosecha debió, desde tiempos muy antiguos, haber sido asociado a ciertos cambios en la posición del sol. En el verano al mediodía el sol sale alto en los cielos, en invierno sí Siempre bajo. Por tanto, nuestra luminaria realiza un movimiento anual hacia arriba y abajo en los cielos, así como un movimiento diurno de ascendencia y ambientación. Pero hay una tercera especie de cambio en la posición del sol, lo cual no es tan obvio, aunque aún así puede ser detectado por unas pocas observaciones cuidadosas, si se combinan con una filosofía hábito de reflexionar. Los primeros observadores de las estrellas apenas pueden hacerlo no se han dado cuenta de que las constelaciones visibles por la noche variaban con la estación del año. Por ejemplo, la brillante figura de Orión, aunque tan bien visto en las noches de invierno, está ausente en verano cielos, y el lugar que ocupaba es entonces ocupado por grupos bastante diferentes de estrellas. Lo mismo puede decirse de otras constelaciones. Cada temporada de El año puede caracterizarse así por los objetos siderales que son llamativo de noche. De hecho, en la antigüedad, era hora de comenzar El ciclo de ocupaciones agrícolas a veces se indicaba por el posición de las constelaciones por la tarde.

Al reflexionar sobre estos hechos, los primeros astrónomos pudieron demuestra el aparente movimiento anual del sol. No podía haber nada Explicación racional de los cambios en las constelaciones con el estaciones, salvo suponiendo que el lugar del sol estaba cambiando, así que como para hacer un circuito completo por los cielos a lo largo del año. Este movimiento solar se confirma mirando hacia el oeste después del atardecer, y mirando las estrellas. A medida que avance la temporada, puede que ocurra Fíjate cada noche que las constelaciones parecen hundirse más y más abajo hacia el oeste, hasta que finalmente se vuelven invisibles desde el Brillo del cielo. La desaparición se explica con la suposición que el sol parece ascender continuamente desde el oeste para encontrarse Las estrellas. Esta moción, por supuesto, no debe confundirse con el subida y puesta diurna ordinaria, en la que todos los cuerpos celestes Participa. Debe entenderse[Pág. 5] que además de verse afectado por el Movimiento común nuestro luminario tiene un movimiento lento e independiente en el dirección opuesta; de modo que, aunque el sol y una estrella puedan ponerse en el A la misma hora hoy, pero como mañana el sol se habrá movido Un poco hacia el este, se deduce que la estrella debe ponerse unos pocos Minutos antes del sol. [1]

Las observaciones pacientes de los primeros astrónomos permitieron que el sol por los cielos se descubrió, y se descubrió que en su circuito entre las estrellas y constelaciones de nuestra luminaria invariablemente siguió el mismo camino. Esto se llama *eclíptica*, y la las constelaciones por las que pasa forman un cinturón alrededor del cielo conocido como el *zodiaco*. Antiguamente se dividía en doce partes iguales porciones o "señales", para que las etapas en el gran viaje del sol pudieran Debe ser convenientemente indicado. La duración del año, o el periodo obligada por el sol a recorrer su curso alrededor de los cielos, parece haber fue averiguado por primera vez por astrónomos cuyos nombres se desconocen. La habilidad de los primeros geómetras orientales quedó aún más evidenciado por su Determinación de la posición de la eclíptica respecto a la ecuador celeste, y por su éxito en la medición del ángulo entre estos dos círculos importantes en los cielos.

También se han observado las características principales del movimiento de la luna con inteligencia en una antigüedad más remota que la historia. El El observador atento percibe la verdad importante de que la luna no ocupa una posición fija en los cielos. Durante el transcurso de un sencillo por la noche, el hecho de que la luna se haya desplazado de oeste a este a través del los cielos pueden percibirse notando su posición relativa a la adyacente estrellas. De hecho, es probable que el movimiento de la luna fuera un descubrimiento antes del movimiento anual del sol, en la medida en que es el consecuencia inmediata de una simple observación, y que implica muy poco ejercicio de cualquier poder intelectual. También en tiempos prehistóricos, la época de la revolución de la luna se habían identificado, y las fases de nuestro El satélite se había atribuido correctamente a este aspecto variable[pág. 6] bajo donde el lado iluminado por el sol está orientado hacia la tierra.

Pero estamos lejos de haber agotado la lista de grandes descubrimientos que han bajado de una antigüedad desconocida. Las explicaciones correctas habían sido dado por el fenómeno llamativo de un eclipse lunar, en el que el la superficie brillante queda temporalmente sumida en la oscuridad, y también de la Un espectáculo aún más imponente de un eclipse solar, en el que el sol ella misma sufre una oscurecimiento parcial o incluso total. Y además, el la agudeza de los primeros astrónomos había detectado las cinco estrellas errantes o planetas: habían rastreado los movimientos de Mercurio y Venus, Marte, Júpiter y Saturno. Habían observado con asombro a los diversos Configuraciones de estos planetas: y igual que el Sol, y en un menor Grado de la Luna, estaban íntimamente ligados a los asuntos cotidianos la vida, así que en la imaginación de estos primeros investigadores los movimientos de los planetas se pensaba que estaban impregnados de bienestar humano o de maldición humana. Finalmente, se percibió un cierto orden que gobernaba lo aparentemente movimientos caprichosos de los planetas. Se descubrió que obedecían ciertas leyes. El cultivo de la ciencia de la geometría fue de la mano Mano con el estudio de la astronomía: y mientras emergemos de la penumbra En la época prehistórica, encontramos que la teoría de los fenómenos de los cielos ya poseían cierto grado de coherencia.

Ptolomeo, siguiendo a Pitágoras, Platón y Aristóteles, reconoció que La figura de la Tierra era globular, y él la demostró con la misma argumentos que empleamos hoy en día. También discernió cómo esto Mighty Globe estaba aislado en el espacio. Admitió que el diurno El movimiento de los cielos podría explicarse por la revolución de la la Tierra en su eje, pero desafortunadamente asignó razones para el rechazo deliberado de esta visión. La tierra, según él, era una carrocería fija; no poseía ni rotación alrededor de un eje ni traslación a través del espacio, pero permanecía constantemente en reposo en lo que se suponía que debía ser el centro del universo. Según la teoría de Ptolomeo, el sol y La Luna se movía en órbitas circulares alrededor de la Tierra en el centro. El [pág. 7]explicación de los movimientos de los planetas que encontró más complicado, porque era necesario tener en cuenta el hecho de que un A veces el planeta avanzaba y a veces retrogradaba. Los antiguos Geómetras se negaban a creer que cualquier movimiento, salvo la revolución, en un era posible para un cuerpo celeste: en consecuencia, un artificio era ideada por la cual cada planeta debía girar en un círculo, de que el centro describía otro círculo alrededor de la tierra.

Aunque ahora se sabe que la doctrina ptolemaica se basa en una gran estimación extravagante de la importancia de la tierra en el esquema de la cielos, sin embargo, hay que admitir que los aparentes movimientos de los los cuerpos celestes pueden explicarse así con considerable precisión. Esta teoría se describe en la gran obra conocida como el "Almagesto", que fue escrita en el siglo II de nuestra era y fue valorada por catorce siglos como la máxima autoridad en todas las cuestiones de astronomía.

Tal era el sistema de astronomía que prevaleció durante la Edad Media, y solo fue desacreditado en una época casi simultánea con la de el descubrimiento del Nuevo

Mundo por Colón. La verdadera disposición de la El sistema solar fue entonces desarrollado por Copérnico en la gran obra a la que Dedicó su vida. El primer principio establecido por estos trabajos se mostró que el movimiento diurno de los cielos se debe a la rotación de La Tierra sobre su eje. Copérnico señaló la diferencia fundamental entre movimientos reales y movimientos aparentes; Demostró que el Apariciones presentadas en El Amanecer y Poniente Diario del Sol y el Las estrellas podrían explicarse por la suposición de que la Tierra rotó, tan satisfactoriamente como por la suposición más engorrosa de Ptolomeo. Además, demostró que esta última suposición debe atribuir a un velocidad casi infinita respecto a las estrellas, de modo que la rotación de la Todo el universo alrededor de la Tierra era claramente una suposición absurda. El segundo gran principio, que ha conferido gloria inmortal a Copérnico asignó a la Tierra su verdadera posición en el universo. Copérnico transfirió el centro, alrededor del cual giran todos los planetas, de la tierra al sol; y estableció la[pág. 8] algo humillante Verdad, que nuestra Tierra es simplemente un planeta que sigue un camino entre los caminos de Venus y Marte, y subordinados como todos los demás planetas al supremo vaivén del Sol.

Esta gran revolución arrasó de la astronomía esas visiones distorsionadas de la la importancia de la Tierra que surgió, quizás no de forma extranatural, del hecho de que que casualmente estamos domiciliados en ese planeta en particular. El los logros de Copérnico pronto fueron seguidos por la invención de el telescopio, ese maravilloso instrumento mediante el cual la ciencia moderna de La astronomía ha sido creada. A la consideración de esto importante Sujeto dedicaremos el primer capítulo de nuestro libro.

PLACA II.
UNA TÍPICA MANCHA SOLAR.
(DESPUÉS LANGLEY.)

[Pág. 9]

CAPÍTULO I.

EL OBSERVATORIO ASTRONÓMICO.

Observaciones astronómicas tempranas—El observatorio de Tycho Brahe—La pupila del ojo—Visión de objetos tenues—El Telescopio—El objeto-vidrio—Ventajas de los grandes telescopios—El Ecuatorial—El observatorio—El poder de un telescopio—Reflejando Telescopios—El Gran Reflector de Lord Rosse en Parsonstown—Cómo el se utiliza el poderoso telescopio—Instrumentos de Precisión—El Meridiano Círculo—Las líneas de araña—Delicia de señalar una Telescopio—Precauciones necesarias para realizar observaciones—El ideal El instrumento y el práctico—La eliminación de Error—Observatorio de Greenwich—El Vidrio de Ópera ordinario como un Instrumento astronómico—La Gran Osa—Contando las Estrellas en el Constelación—Cómo convertirse en un Observador.

Los primeros rudimentos del Observatorio Astronómico son tan pequeños conocidos como los primeros descubrimientos en la astronomía misma. Probablemente el Primera aplicación de la observación instrumental a los cuerpos celestes consistía en la simple operación de medir la sombra de un poste proyectado Al sol al mediodía. Las variaciones en la longitud de esta sombra permitió a los astrónomos primitivos investigar los movimientos aparentes del sol. Pero incluso en tiempos muy antiguos la astronómica especial Se emplearon instrumentos con suficiente precisión para añadir a la cantidad de conocimientos astronómicos, y mostró un considerable conocimiento ingenio por parte de los diseñadores.

El profesor Newcomb[2] escribe así: "El líder fue Tycho Brahe, quien fue nacido en 1546, tres años después de la muerte de Copérnico. Su atención se dirigió por primera vez al estudio de la astronomía por un eclipse de sol en 21 de agosto de 1560, que fue total en algunas partes de Europa. Asombrado Para que tal fenómeno pudiera predecirse, se dedicó a un estudio de los métodos de observación y cálculo mediante[pág. 10] que la predicción se hizo. En 1576 el rey de Dinamarca fundó el célebre observatorio de Uraniborg, en la que Tycho pasó veinte años dedicándose con esmero observaciones de las posiciones de los cuerpos celestes con los mejores instrumentos que luego podrían fabricarse. Esto fue justo antes de la invención del telescopio, de modo que el astrónomo no podía beneficiarse de eso instrumento potente. En consecuencia, sus observaciones fueron superadas por las mejoradas de los siglos siguientes, y su fama y la importancia se debe principalmente a que le proporcionaron a Kepler los medios de descubrir sus célebres leyes del movimiento planetario."

La dirección del telescopio hacia el cielo por Galileo dio una maravilla impulso al estudio de los cuerpos celestes. Este hombre extraordinario es destacado en la historia de la astronomía, no solo por su conexión con esta invención suprema, pero también por sus logros en la Partes abstractas de la astronomía. Nació en Pisa en 1564 y en 1609 Se construyó el primer telescopio utilizado para la observación astronómica. Galileo murió en 1642, el año en que nació Newton. Fue Galileo que sentó con solidez los cimientos de esa ciencia de la Dinámica, de cuál astronomía es la ilustración más espléndida; y fue él quien, por promulgando las doctrinas enseñadas por Copérnico, incurrió en la ira de la Inquisición.

La estructura del ojo humano en la medida en que se adapta exquisitamente El alumno es preocupado nos presenta una ilustración adecuada de la Principio del telescopio. Para ver un objeto, es necesario que el la luz que sale debería entrar en el ojo. El portal por el que la luz es admitido como alumno. Durante el día, cuando la luz es intensa, el El iris disminuye el tamaño de la pupila y, por tanto, evita demasiada luz de entrar. Por la noche, o cuando la luz es escasa, el ojo suele hacerlo requiere comprender todo lo que pueda. La pupila entonces se expande; Cada vez más la luz se admite según la pupila crece. La iluminación de la imagen en la retina se controla así de forma efectiva con los requisitos de la visión.

Una estrella nos transmite sus débiles rayos de luz, y desde[pág. 11] esos rayos La imagen se forma. Incluso con la pupila más abierta, puede que, sin embargo, ocurre que la imagen no es lo suficientemente brillante como para excitar a Sensación de visión. Aquí el telescopio viene en nuestra ayuda: atrapa a todos los rayos en un haz cuyas dimensiones originales eran demasiado grandes para permitir de su admisión a través del alumno. La acción de los objetivos concentra esos rayos en un arroyo lo suficientemente delgado como para atravesar el Pequeña abertura. Por tanto, tenemos el brillo de la imagen en la retina intensificado. Está iluminado con casi tanta luz como lo estaría recogido del mismo objeto a través de una pupila tan grande como el gran lentes del telescopio.

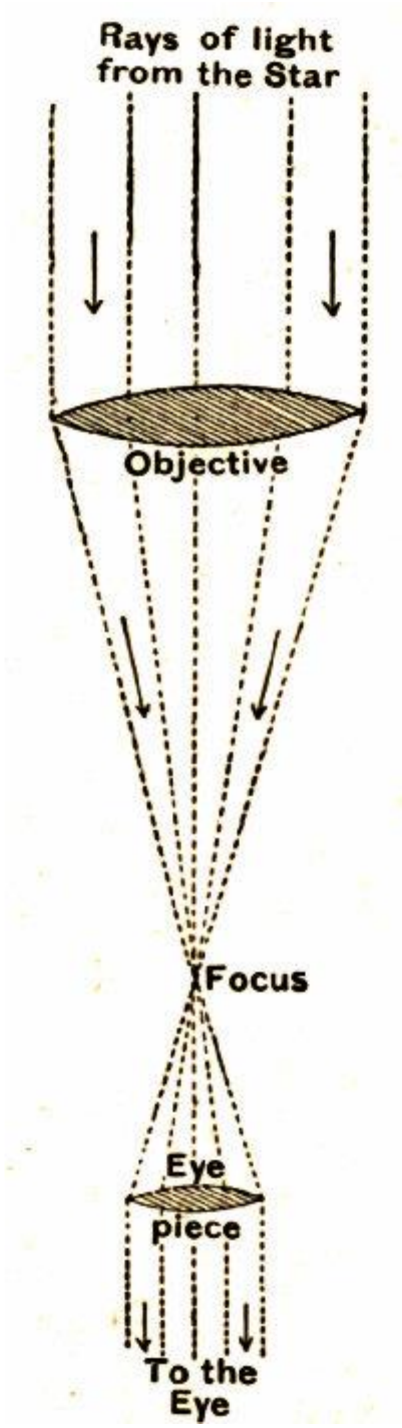


Fig. 1.—Principio del telescopio refractor.

En los observatorios astronómicos empleamos telescopios de dos completamente Diferentes clases. Las formas más conocidas son las conocidas como *refractores*, en las que la operación de condensar los rayos de luz es realizada por refracción. El carácter del refractor se muestra en la Fig. 1. Los rayos de la estrella caen sobre el objeto-vidrio al final de la y al atravesar se refractan en un haz convergente, de modo que todos se intersectan en el foco. Divergente de a continuación, los rayos encuentran el ocular, que tiene el efecto de restaurándolos al paralelismo. La gran viga cilíndrica que vertida Hacia abajo, el objeto-vidrio se ha condensado así en uno pequeño, que puede entrar en la pupila. Sin embargo, debe añadirse que el compuesto La naturaleza de la luz requiere una forma más compleja de objeto-vidrio que la Lente simple aquí mostrada. En un telescopio refractor tenemos que emplear qué se conoce como la combinación acromática, que consiste en una lente de pedernal Cristal y uno de cristal corona, ajustados para adaptarse mutuamente con extremos Cuidado.

[pág. 12]

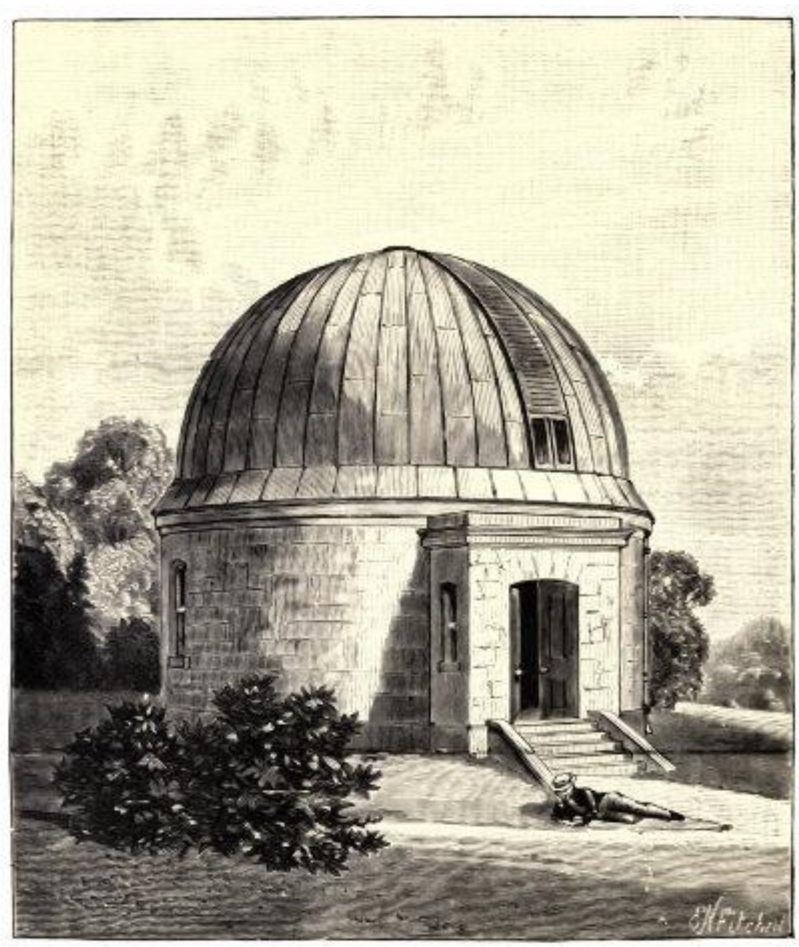


Fig. 2.—La cúpula del Ecuatorial Sur en Dunsink Observatorio Condado de Dublín.

[Pág. 13]

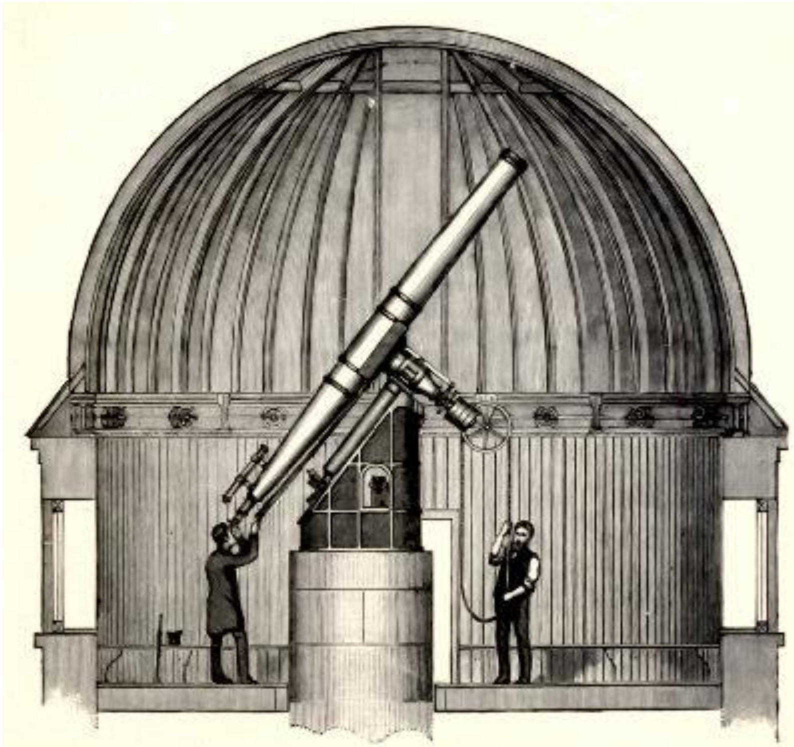
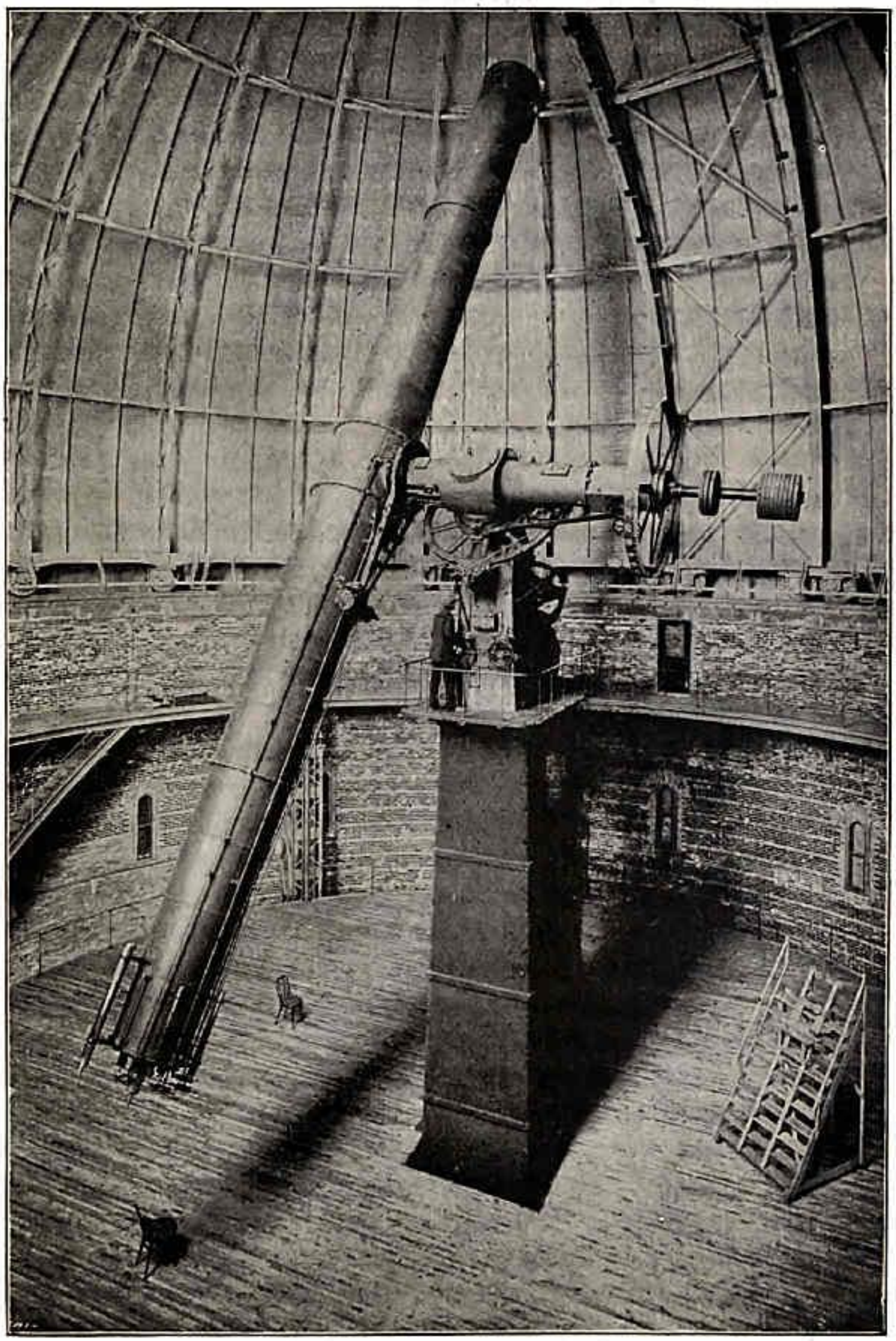


Fig. 3.—Sección de la cúpula del observatorio de Dunsink.

La apariencia de un observatorio astronómico, diseñado para acomodar un instrumento de dimensiones moderadas se muestra en las figuras adjuntas. La primera (Fig. 2) representa la cúpula erigida en el Observatorio de Dunsink para el telescopio ecuatorial, cuyo objeto de vidrio se presentó a la Junta del Trinity College de Dublín, por el difunto Sir James South. El La parte principal del edificio es un muro cilíndrico, en cuya parte superior reposa un tejado hemisférico. En este tejado hay una contraventana, que puede ser abierto para permitir que el telescopio en el interior obtuviera una vista de los cielos. La cúpula puede girar para que la abertura pueda ser girado hacia esa parte del cielo donde está el objeto situado. La siguiente vista (Fig. 3) muestra una sección a través de la cúpula, mostrando la maquinaria por la que el asistente la hace girar, como bueno, así como el propio telescopio. El ojo del observador se coloca en el ocular, y se le representa en el acto de girar una manilla, que tiene el poder de mover lentamente el telescopio para ajustar el Instrumento con precisión sobre el cuerpo celeste que se desea Observa. Las dos lentes que juntas forman el objeto-vidrio de este los instrumentos tienen doce pulgadas de diámetro, y la calidad del El telescopio depende principalmente de la precisión con la que[Pág. 14] estos objetivos tienen se ha forjado. El ocular es un asunto relativamente sencillo. Es consiste únicamente en una o dos pequeñas lentes; y varios oculares pueden se emplea según el poder de aumento que se desee. Es se observa que para muchos fines astronómicos se magnifica los poderes no son deseables. También existe un límite, más allá del cual la magnificación no puede llevarse con ventaja. El objeto-vidrio puede solo recoge una cierta cantidad de luz de la estrella; y si el El poder de aumento sería demasiado grande, esta cantidad limitada de luz será dispersado finamente sobre una superficie demasiado grande, se encontrará el resultado insatisfactorio. La inestabilidad de la atmósfera limita aún más hasta qué punto la imagen puede ampliarse ventajosamente, para cada el aumento de potencia aumenta en el mismo grado que la atmósfera Disturbios.

Un telescopio montado de la manera que se muestra aquí se llama *ecuatorial*. La comodidad de este peculiar estilo de soporte del instrumento consiste en la facilidad con la que el telescopio puede moverse de tal manera que Sigue a una estrella en su aparente viaje por el cielo. Lo necesario Los movimientos del tubo se determinan mediante un mecanismo de relojería accionado por un peso, por lo que que, una vez que el instrumento ha sido correctamente apuntado, la estrella permanecer en el campo de visión del observador, y el efecto de lo aparente El movimiento diurno será neutralizado. El último refinamiento en esto dirección es la aplicación de un sistema eléctrico mediante el cual el la conducción del instrumento se controla desde el reloj estándar de la observatorio.

[Pág. 15]



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ig. 4.—El telescopio en el Observatorio Yerkes, Chicago.
(*Del Astrophysical Journal, Vol. VI, Nº 1.)*

[Pág. 16]

La potencia de un telescopio refractor —en la medida en que la expresión tenga alguna significado definido—debe medirse por el diámetro de su objeto-vidrio. De hecho, ha habido cierta honorable rivalidad entre los distintos civilizadas naciones sobre cuál debería poseer la mayor capacidad de reacción telescopio. Entre los instrumentos más destacados que han tenido éxito terminada es la erigida en 1881 por Sir Howard Grubb, de Dublín, en la espléndido observatorio en Viena. Sus dimensiones pueden estimarse a partir de el hecho, el vidrio-objeto tiene dos pies y tres pulgadas de diámetro. Muchos ingeniosos ingeniosos recursos ayudan a reducir las molestias que conlleva el uso de un instrumento de proporciones tan vastas. Entre ellos nosotros aquí puede observar el método por el cual los círculos graduados se adjuntan a los telescopios se acercan al campo de visión del observador. Estos círculos son necesariamente situado en partes del instrumento que están alejadas de el ocular donde está destinado el observador. Las delicadas marcas y Sin embargo, las figuras se pueden leer fácilmente desde lejos por un pequeño auxiliar telescopio, que, mediante reflectores adecuados, conduce los rayos de luz desde los círculos hasta el ojo del observador.

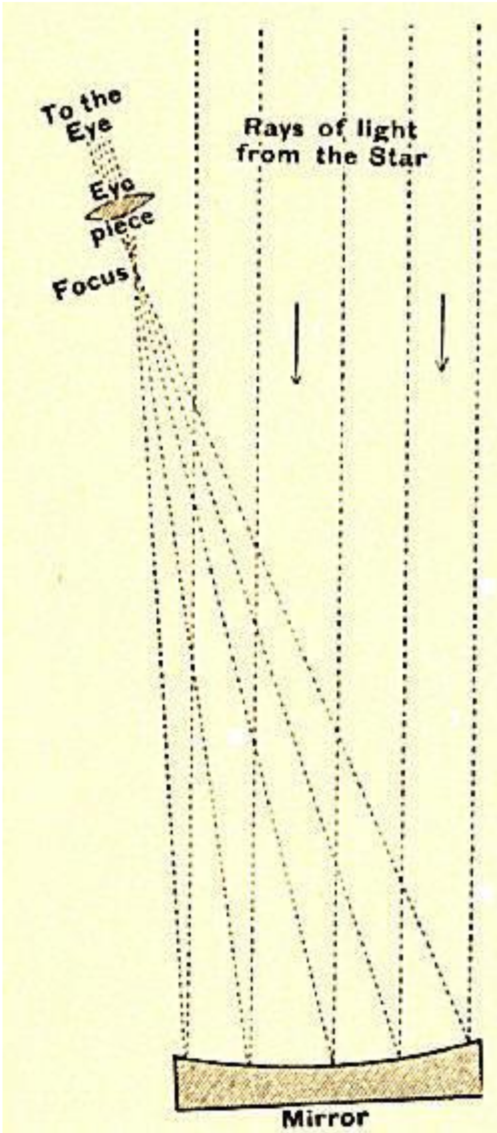

Fig. 5.—Principle of Herschel's Refracting Telescope.

Numerosos telescopios refractores de exquisita perfección han sido producido por los señores Alvan Clark, de Cambridgeport, Boston, Massachusetts. Uno de su telescopio más famoso es el gran refractor Lick, que actualmente se utiliza en Monte Hamilton en California. El diámetro de este objeto-vidrio es treinta y seis pulgadas, y su distancia focal es de cincuenta y seis pies dos pulgadas. A Recientemente la misma empresa ha hecho un esfuerzo aún mayor en la refractor de cuarenta pulgadas de apertura para el Observatorio Yerkes de la Universidad de Chicago. El telescopio, que tiene setenta y cinco pies de profundidad se monta bajo una cúpula giratoria de noventa pies de diámetro, y para permitir que el observador alcance el ocular sin usar escaleras muy grandes, el suelo de la sala puede subirse y bajarse a través de un alcance de veintidós pies por motores eléctricos. Esto se muestra en Fig. 4, mientras que la fachada sur del Observatorio Yerkes está representada en la Fig. 6.

[pág. 17]

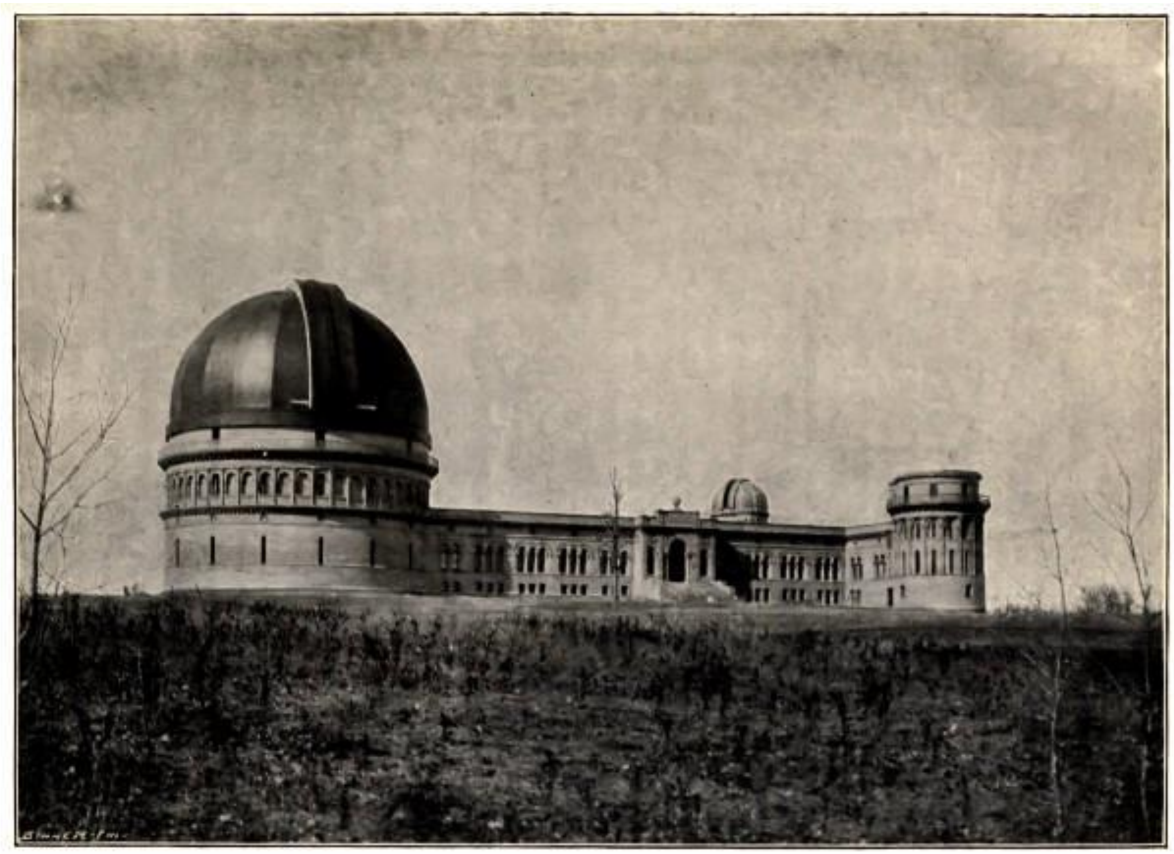

Fig. 6.—South Front of the Yerkes Observatory, Chicago.
(*From the Astrophysical Journal, Vol. vi., No. 1.*)

[Pg 18]

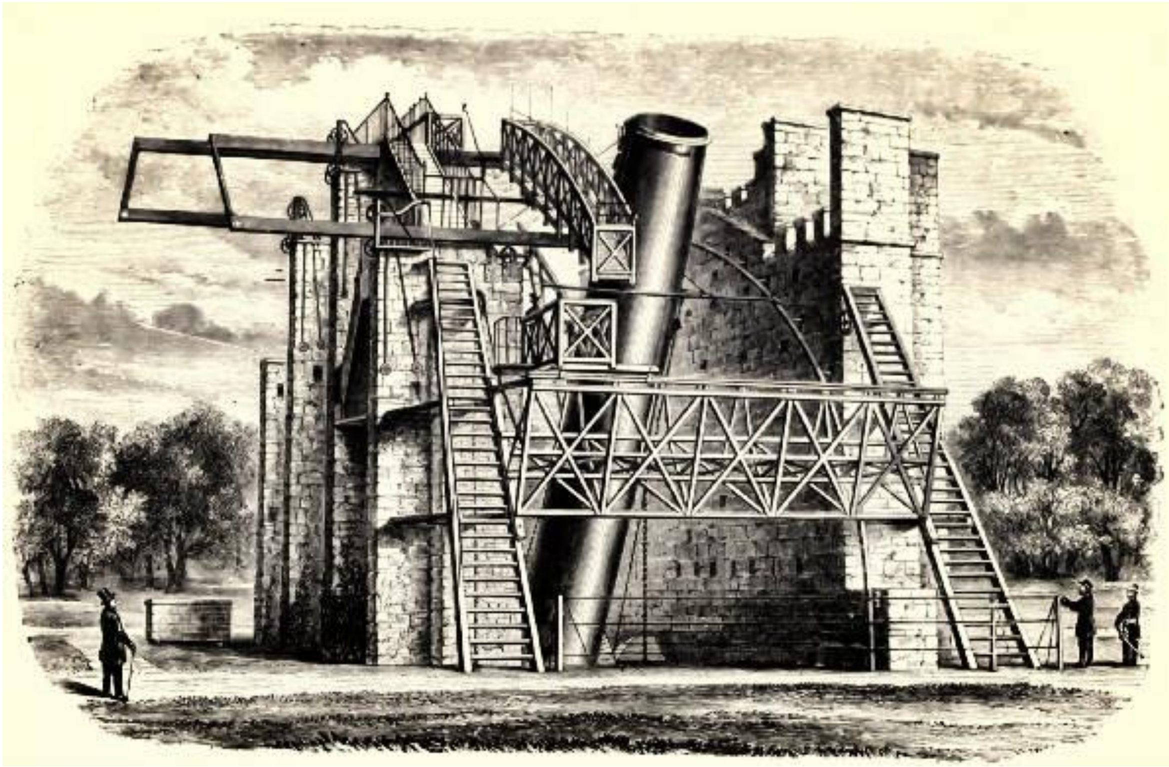

Fig. 7.—Lord Rosse's Telescope.

Within the last few years two fine telescopes have been added to the instrumental equipment of the Royal Observatory, Greenwich, both by Sir H. Grubb. One of these, containing a 28-inch object-glass, has been erected on a mounting originally constructed for a smaller instrument by Sir G. Airy. The other, presented by Sir Henry Thompson, is of 26 inches aperture, and is adapted for photographic work.

There is a limit to the size of the refractor depending upon the material of the object-glass. Glass manufacturers seem to experience unusual difficulties in their attempts to form large discs of optical glass pure enough and uniform enough to be suitable for telescopes. These difficulties are enhanced with every increase in the size of the discs, so that the cost has a tendency to increase at a very much greater rate. It may be mentioned in illustration that the price paid for the object-glass of the Lick telescope exceeded ten thousand pounds.

There is, however, an alternative method of constructing a telescope, in which the difficulty we have just mentioned does not arise. The principle of the simplest form of *reflector* is shown in Fig. 5, which represents what is called the Herschelian instrument. The rays of light from the star under observation fall on a mirror which is both carefully shaped and highly polished. After reflection, the rays proceed to a focus, and diverging from thence, fall on the eye-piece, by which they are restored to parallelism, and thus become adapted for reception in the eye. It was essentially on this principle (though with a secondary flat mirror at the upper end of the tube reflecting the rays at a right angle to the side of the tube, where the eye-piece is placed) that Sir Isaac Newton constructed the little reflecting telescope which is now treasured by the Royal Society. A famous instrument of the Newtonian type was built, half a century ago, by the late Earl of Rosse, at Parsonstown. It is represented in Fig. 7. The colossal aperture of this instrument has never been surpassed; it has, indeed, never been rivalled. The mirror or speculum, as it is often called, is a thick metallic disc, composed of a mixture of two parts of copper with one of tin. This alloy is so hard and brittle as to make the necessary mechanical operations difficult to manage. The material admits, however, of a brilliant polish, and of receiving and retaining an accurate figure. The Rosse speculum—six feet in diameter and three tons in weight—reposes at the lower end of a telescope fifty-five feet long. The tube is suspended between two massive castellated walls, which form an imposing feature on the lawn at Birr Castle. This instrument cannot be turned about towards every part of the sky, like the equatorials we have recently been considering. The great tube is only capable of elevation in altitude along the meridian, and of a small lateral movement east and west of the meridian. Every star or nebula visible in the latitude of Parsonstown (except those very near the pole) can, however, be observed in the great telescope, if looked for at the right time.

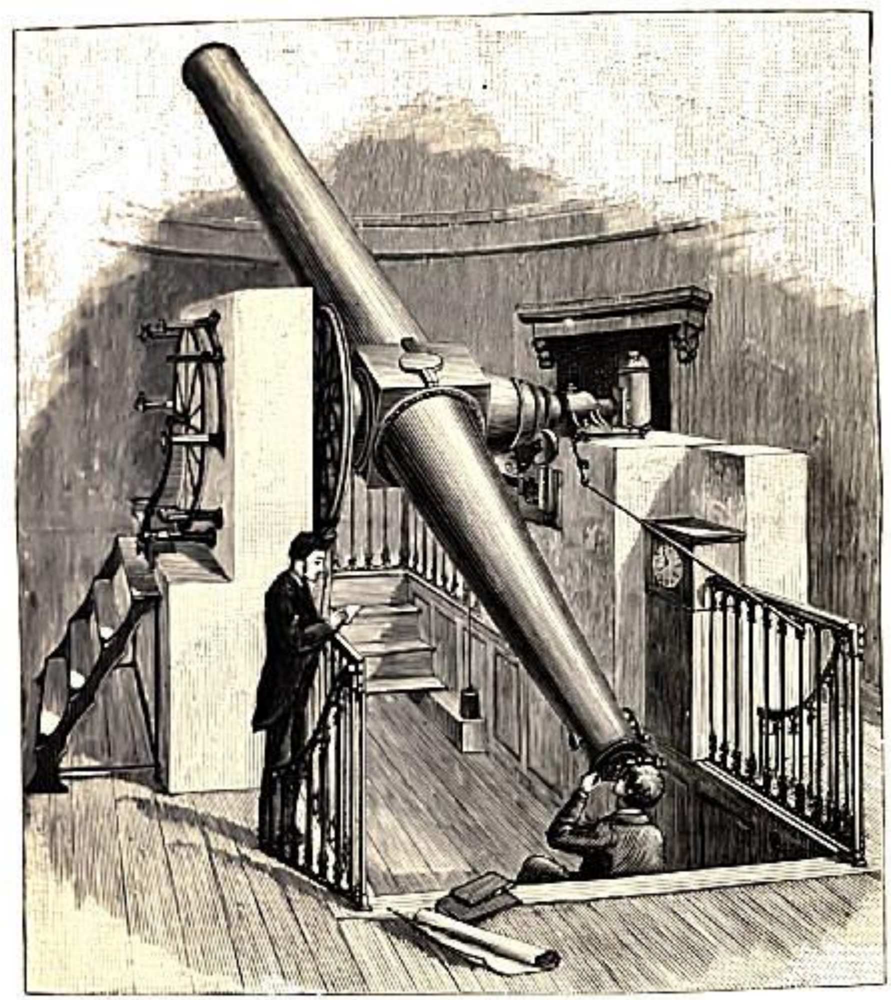

Fig. 8.—Meridian Circle.

Before the object reaches the meridian, the telescope must be adjusted at the right elevation. The necessary power is transmitted by a chain from a winch at the northern end of the walls to a point near the upper end of the tube. By this contrivance the telescope can be raised or lowered, and an ingenious system of counterpoises renders the movement equally easy at all altitudes. The observer then takes his station in one of the galleries which give access to the eye-piece; and when the right moment has arrived, the star enters the field of view. Powerful mechanism drives the great instrument, so as to counteract the diurnal movement, and thus the observer can retain the object in view until he has made his measurements or finished his drawing.

Of late years reflecting telescopes have been generally made with mirrors of glass covered with a thin film of silver, which is capable of reflecting much more light than the surface of a metallic mirror. Among great reflectors of this kind we may mention two, of three and five feet aperture respectively, with which Dr. Common has done valuable work.

We must not, however, assume that for the general work in an observatory a colossal instrument is the most suitable. The mighty reflector, or refractor, is chiefly of use where unusually faint objects are being examined. For work in which accurate measurements are made of objects not particularly difficult to see, telescopes of smaller dimensions are more suitable. The fundamental facts about the heavenly bodies have been chiefly learned from observations obtained with instruments of moderate optical power, specially furnished so as to enable precise measures of position to be secured. Indeed, in the early stages of astronomy, important determinations of position were effected by contrivances[Pg 22] which showed the direction of the object without any telescopic aid.

Perhaps the most valuable measurements obtained in our modern observatories are yielded by that instrument of precision known as the *meridian circle*. It is impossible, in any adequate account of the Story of the Heavens, to avoid some reference to this indispensable aid to astronomical research, and therefore we shall give a brief account of one of its simpler forms, choosing for this purpose a great instrument in the Paris Observatory, which is represented in Fig. 8.

The telescope is attached at its centre to an axis at right angles to its length. Pivots at each extremity of this axis rotate upon fixed bearings, so that the movements of the telescope are completely restricted to the plane of the meridian. Inside the eye-piece of the telescope extremely fine vertical fibres are stretched. The observer watches the moon, or star, or planet enter the field of view; and he notes by the clock the exact time, to the fraction of a second, at which the object passes over each of the lines. A silver band on the circle attached to the axis is divided into degrees and subdivisions of a degree, and as this circle moves with the telescope, the elevation at which the instrument is pointed will be indicated. For reading the delicately engraved marks and figures on the silver, microscopes are necessary. These are shown in the sketch, each one being fixed into an aperture in the wall which supports one end of the instrument. At the opposite side is a lamp, the light from which passes through the perforated axis of the pivot, and is thence ingeniously deflected by mirrors so as to provide the requisite illumination for the lines at the focus.

The fibres which the observer sees stretched over the field of view of the telescope demand a few words of explanation. We require for this purpose a material which shall be very fine and fairly durable, as well as somewhat elastic, and of no appreciable weight. These conditions cannot be completely fulfilled by any metallic wire, but they are exquisitely realised in the beautiful thread which is spun by the spider. The[Pg 23] delicate fibres are stretched with nice skill across the field of view of the telescope, and cemented in their proper places. With instruments so beautifully appointed we can understand the precision attained in modern observations. The telescope is directed towards a star, and the image of the star is a minute point of light. When that point coincides with the intersection of the two central spider lines the telescope is properly sighted. We use the word sighted designedly, because we wish to suggest a comparison between the sighting of a rifle at the target and the sighting of a telescope at a star. Instead of the ordinary large bull's-eye, suppose that the target only consisted of a watch-dial, which, of course, the rifleman could not see at the distance of any ordinary range. But with the telescope of the meridian circle the watch-dial would be visible even at the distance of a mile. The meridian circle is indeed capable of such precision as a sighting instrument that it could be pointed separately to each of two stars which subtend at the eye an angle no greater than that subtended by an adjoining pair of the sixty minute dots around the circumference of a watch-dial a mile distant from the observer.

This power of directing the instrument so accurately would be of but little avail unless it were combined with arrangements by which, when once the telescope has been pointed correctly, the position of the star can be ascertained and recorded. One element in the determination of the position is secured by the astronomical clock, which gives the moment when the object crosses the central vertical wire; the other element is given by the graduated circle which reads the angular distance of the star from the zenith or point directly overhead.

Superb meridian instruments adorn our great observatories, and are nightly devoted to those measurements upon which the great truths of astronomy are mainly based. These instruments have been constructed with refined skill; but it is the duty of the painstaking astronomer to distrust the accuracy of his instrument in every conceivable way. The great tube may be as rigid a structure as mechanical engineers can produce; the graduations on the circle may[Pg 24] have been engraved by the most perfect of dividing machines; but the conscientious astronomer will not be content with mere mechanical precision. That meridian circle which, to the uninitiated, seems a marvellous piece of workmanship, possessing almost illimitable accuracy, is viewed in a very different light by the astronomer who makes use of it. No one can appreciate more fully than he the skill of the artist who has made that meridian circle, and the beautiful contrivances for illumination and reading off which give to the instrument its perfection; but while the astronomer recognises the beauty of the actual machine he is using, he has always before his mind's eye an ideal instrument of absolute perfection, to which the actual meridian circle only makes an approximation.

Contrasted with the ideal instrument, the finest meridian circle is little more than a mass of imperfections. The ideal tube is perfectly rigid, the actual tube is flexible; the ideal divisions of the circle are perfectly uniform, the actual divisions are not uniform. The ideal instrument is a geometrical embodiment of perfect circles, perfect straight lines, and perfect right angles; the actual instrument can only show approximate circles, approximate straight lines, and approximate right angles. Perhaps the spider's part of the work is on the whole the best; the stretched web gives us the nearest mechanical approach to a perfectly straight line; but we mar the spider's work by not being able to insert those beautiful threads with perfect uniformity, while our attempts to adjust two of them across the field of view at right angles do not succeed in producing an angle of exactly ninety degrees.

Nor are the difficulties encountered by the meridian observer due solely to his instrument. He has to contend against his own imperfections; he has often to allow for personal peculiarities of an unexpected nature; the troubles that the atmosphere can give are notorious; while the levelling of his instrument warns him that he cannot even rely on the solid earth itself. We learn that the earthquakes, by which the solid ground is sometimes disturbed, are merely[Pg 25] the more conspicuous instances of incessant small movements in the earth which every night in the year derange the delicate adjustment of the instrument.

When the existence of these errors has been recognised, the first great step has been taken. By an alliance between the astronomer and the mathematician it is possible to measure the discrepancies between the actual meridian circle and the instrument that is ideally perfect. Once this has been done, we can estimate the effect which the irregularities produce on the observations, and finally, we succeed in purging the observations from the grosser errors by which they are contaminated. We thus obtain results which are not indeed mathematically accurate, but are nevertheless close approximations to those which would be obtained by a perfect observer using an ideal instrument of geometrical accuracy, standing on an earth of absolute rigidity, and viewing the heavens without the intervention of the atmosphere.

In addition to instruments like those already indicated, astronomers have other means of following the motions of the heavenly bodies. Within the last fifteen years photography has commenced to play an important part in practical astronomy. This beautiful art can be utilised for representing many objects in the heavens by more faithful pictures than the pencil of even the most skilful draughtsman can produce. Photography is also applicable for making charts of any region in the sky which it is desired to examine. When repeated pictures of the same region are made from time to time, their comparison gives the means of ascertaining whether any star has moved during the interval. The amount and direction of this motion may be ascertained by a delicate measuring apparatus under which the photographic plate is placed.

If a refracting telescope is to be used for taking celestial photographs, the lenses of the object-glass must be specially designed for this purpose. The rays of light which imprint an image on the prepared plate are not exactly the same as those which are chiefly concerned in the production of the image on the retina of the human eye. A reflecting mirror, however, brings all the rays, both those which are chemically[Pg 26] active and those which are solely visual, to one and the same focus. The same reflecting instrument may therefore be used either for looking at the heavens or for taking pictures on a photographic plate which has been substituted for the observer's eye.

A simple portrait camera has been advantageously employed for obtaining striking photographs of larger areas of the sky than can be grasped in a long telescope; but for purposes of accurate measurement those taken with the latter are incomparably better.

It is needless to say that the photographic apparatus, whatever it may be, must be driven by delicately-adjusted clockwork to counteract the apparent daily motion of the stars caused by the rotation of the earth. The picture would otherwise be spoiled, just as a portrait is ruined if the sitter does not remain quiet during the exposure.

Among the observatories in the United Kingdom the Royal Observatory at Greenwich is of course the most famous. It is specially remarkable among all the similar institutions in the world for the continuity of its labours for several generations. Greenwich Observatory was founded in 1675 for the promotion of astronomy and navigation, and the observations have from the first been specially arranged with the object of determining with the greatest accuracy the positions of the principal fixed stars, the sun, the moon, and the planets. In recent years, however, great developments of the work of the Observatory have been witnessed, and the most modern branches of the science are now assiduously pursued there.

The largest equatorial at Greenwich is a refractor of twenty-eight inches aperture and twenty-eight feet long, constructed by Sir Howard Grubb. A remarkable composite instrument from the same celebrated workshop has also been recently added to our national institution. It consists of a great refractor specially constructed for photography, of twenty-six inches aperture (presented by Sir Henry Thompson) and a reflector of thirty inches diameter, which is the product of Dr. Common's skill. The huge volume published[Pg 27] annually bears witness to the assiduity with which the Astronomer Royal and his numerous staff of assistant astronomers make use of the splendid means at their disposal.

The southern part of the heavens, most of which cannot be seen in this country, is watched from various observatories in the southern hemisphere. Foremost among them is the Royal Observatory at the Cape of Good Hope, which is furnished with first-class instruments. We may mention a great photographic telescope, the gift of Mr. M'Clean. Astronomy has been greatly enriched by the many researches made by Dr. Gill, the director of the Cape Observatory.

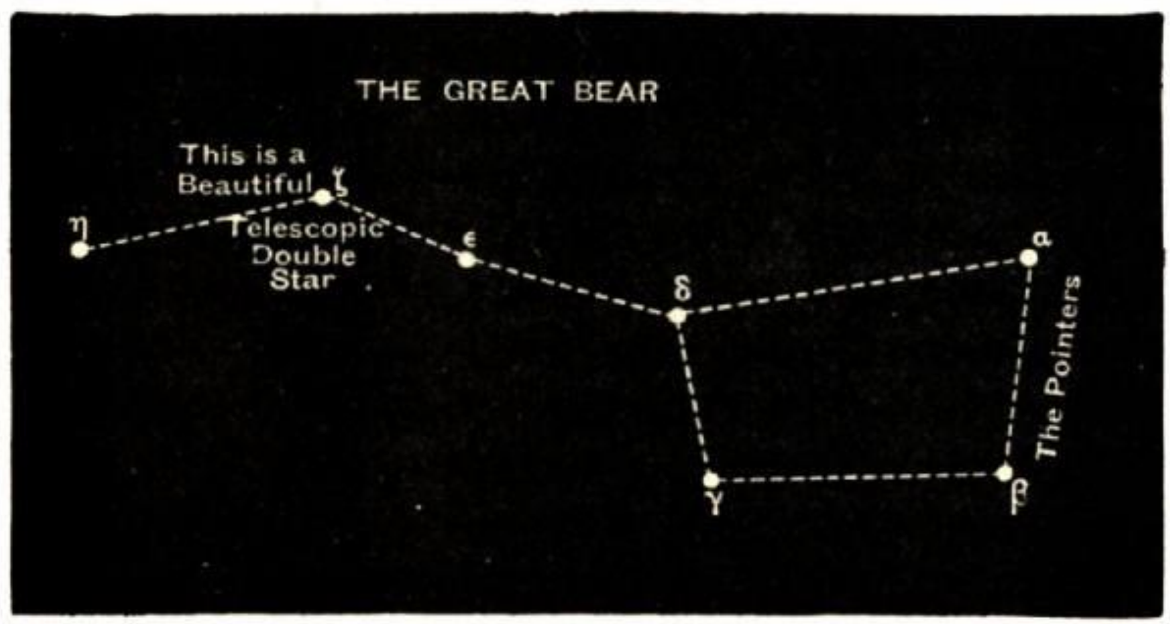

Fig. 9.—The Great Bear.

It is not, however, necessary to use such great instruments to obtain some idea of the aid the telescope will afford. The most suitable instrument for commencing astronomical studies is within ordinary reach. It is the well-known binocular that a captain uses on board ship; or if that cannot be had, then the common opera-glass will answer nearly as well. This is, no doubt, not so powerful as a telescope, but it has some compensating advantages. The opera-glass will enable us to survey a large region of the sky at one glance, while a telescope, generally speaking, presents a much smaller field of view.

Let us suppose that the observer is provided with an opera-glass and is about to commence his astronomical studies.[Pg 28] The first step is to become acquainted with the conspicuous group of seven stars represented in Fig. 9. This group is often called the Plough, or Charles's Wain, but astronomers prefer to regard it as a portion of the constellation of the Great Bear (Ursa Major). There are many features of interest in this constellation, and the beginner should learn as soon as possible to identify the seven stars which compose it. Of these the two marked α and β, at the head of the Bear, are generally called the "pointers." They are of special use, because they serve to guide the eye to that most important star in the whole sky, known as the "pole star."

Fix the attention on that region in the Great Bear, which forms a sort of rectangle, of which the stars α β γ δ are the corners. The next fine night try to count how many stars are visible within that rectangle. On a very fine night, without a moon, perhaps a dozen might be perceived, or even more, according to the keenness of the eyesight. But when the opera-glass is directed to the same part of the constellation an astonishing sight is witnessed. A hundred stars can now be seen with the greatest ease.

But the opera-glass will not show nearly all the stars in this region. Any good telescope will reveal many hundreds too faint for the feebler instrument. The greater the telescope the more numerous the stars: so that seen through one of the colossal instruments the number would have to be reckoned in thousands.

We have chosen the Great Bear because it is more generally known than any other constellation. But the Great Bear is not exceptionally rich in stars. To tell the number of the stars is a task which no man has accomplished; but various estimates have been made. Our great telescopes can probably show at least 50,000,000 stars.

The student who uses a good refracting telescope, having an object-glass not less than three inches in diameter, will find occupation for many a fine evening. It will greatly increase the interest of his work if he have the charming handbook of the heavens known as Webb's "Celestial Objects for Common Telescopes."

CHAPTER II.

THE SUN.

The vast Size of the Sun—Hotter than Melting Platinum—Is the Sun the Source of Heat for the Earth?—The Sun is 92,900,000 miles distant—How to realise the magnitude of this distance—Day and Night—Luminous and Non-Luminous Bodies—Contrast between the Sun and the Stars—The Sun a Star—Granulated Appearance of the Sun—The Spots on the Sun—Changes in the Form of a Spot—The Faculæ—The Rotation of the Sun on its Axis—View of a Typical Sun-Spot—Periodicity of the Sun-Spots—Connection between the Sun-Spots and Terrestrial Magnetism—Principles of Spectrum Analysis—Substances present in the Sun—Spectrum of a Spot—The Prominences surrounding the Sun—Total Eclipse of the Sun—Size and Movement of the Prominences—Their connection with the Spots—Spectroscopic Measurement of Motion on the Sun—The Corona surrounding the Sun—Constitution of the Sun.

In commencing our examination of the orbs which surround us, we naturally begin with our peerless sun. His splendid brilliance gives him the pre-eminence over all other celestial bodies.

The dimensions of our luminary are commensurate with his importance. Astronomers have succeeded in the difficult task of ascertaining the exact figures, but they are so gigantic that the results are hard to realise. The diameter of the orb of day, or the length of the axis, passing through the centre from one side to the other, is 866,000 miles. Yet this bare statement of the dimensions of the great globe fails to convey an adequate idea of its vastness. If a railway were laid round the sun, and if we were to start in an express train moving sixty miles an hour, we should have to travel for five years without intermission night or day before we had accomplished the journey.

When the sun is compared with the earth the bulk of our luminary becomes still more striking. Suppose his globe[Pg 30] were cut up into one million parts, each of these parts would appreciably exceed the bulk of our earth. Fig. 10 exhibits a large circle and a very small one, marked S and E respectively. These circles show the comparative sizes of the two bodies. The mass of the sun does not, however, exceed that of the earth in the same proportion. Were the sun placed in one pan of a mighty weighing balance, and were 300,000 bodies as heavy as our earth placed in the other, the luminary would turn the scale.

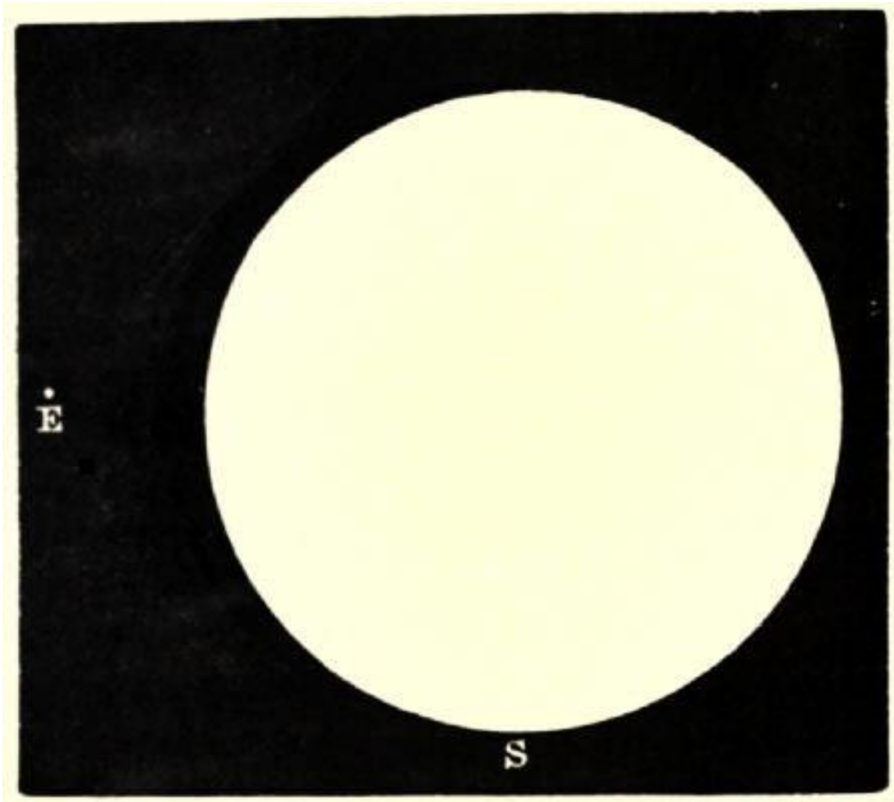

Fig. 10.—Comparative Size of the Earth and the Sun.

The sun has a temperature far surpassing any that we artificially produce, either in our chemical laboratories or our metallurgical establishments. We can send a galvanic current through a piece of platinum wire. The wire first becomes red hot, then white hot; then it glows with a brilliance almost dazzling until it fuses and breaks. The temperature of the melting platinum wire could hardly be surpassed in the most elaborate furnaces, but it does not attain the temperature of the sun.

It must, however, be admitted that there is an apparent discrepancy between a fact of common experience and the[Pg 31] statement that the sun possesses the extremely high temperature that we have just tried to illustrate. "If the sun were hot," it has been said, "then the nearer we approach to him the hotter we should feel; yet this does not seem to be the case. On the top of a high mountain we are nearer to the sun, and yet everybody knows that it is much colder up there than in the valley beneath. If the mountain be as high as Mont Blanc, then we are certainly two or three miles nearer the glowing globe than we were at the sea-level; yet, instead of additional warmth, we find eternal snow." A simple illustration may help to lessen this difficulty. In a greenhouse on a sunshiny day the temperature is much hotter than it is outside. The glass will permit the hot sunbeams to enter, but it refuses to allow them out again with equal freedom, and consequently the temperature rises. The earth may, from this point of view, be likened to a greenhouse, only, instead of the panes of glass, our globe is enveloped by an enormous coating of air. On the earth's surface, we stand, as it were, inside the greenhouse, and we benefit by the interposition of the atmosphere; but when we climb very high mountains, we gradually pass through some of the protecting medium, and then we suffer from the cold. If the earth were deprived of its coat of air, it seems certain that eternal frost would reign over whole continents as well as on the tops of the mountains.

The actual distance of the sun from the earth is about 92,900,000 miles; but by merely reciting the figures we do not receive a vivid impression of the real magnitude. It would be necessary to count as quickly as possible for three days and three nights before one million was completed; yet this would have to be repeated nearly ninety-three times before we had counted all the miles between the earth and the sun.

Every clear night we see a vast host of stars scattered over the sky. Some are bright, some are faint, some are grouped into remarkable forms. With regard to this multitude of brilliant points we have now to ask an important question. Are they bodies which shine by their own light like the sun,[Pg 32] or do they only shine with borrowed light like the moon? The answer is easily stated. Most of those bodies shine by their own light, and they are properly called *stars*.

Suppose that the sun and the multitude of stars, properly so called, are each and all self-luminous brilliant bodies, what is the great distinction between the sun and the stars? There is, of course, a vast and obvious difference between the unrivalled splendour of the sun and the feeble twinkle of the stars. Yet this distinction does not necessarily indicate that our luminary has an intrinsic splendour superior to that of the stars. The fact is that we are nestled up comparatively close to the sun for the benefit of his warmth and light, while we are separated from even the nearest of the stars by a mighty abyss. If the sun were gradually to retreat from the earth, his light would decrease, so that when he had penetrated the depths of space to a distance comparable with that by which we are separated from the stars, his glory would have utterly departed. No longer would the sun seem to be the majestic orb with which we are familiar. No longer would he be a source of genial heat, or a luminary to dispel the darkness of night. Our great sun would have shrunk to the insignificance of a star, not so bright as many of those which we see every night.

Momentous indeed is the conclusion to which we are now led. That myriad host of stars which studs our sky every night has been elevated into vast importance. Each one of those stars is itself a mighty sun, actually rivalling, and in many cases surpassing, the splendour of our own luminary. We thus open up a majestic conception of the vast dimensions of space, and of the dignity and splendour of the myriad globes by which that space is tenanted.

There is another aspect of the picture not without its utility. We must from henceforth remember that our sun is only a star, and not a particularly important star. If the sun and the earth, and all which it contains, were to vanish, the effect in the universe would merely be that a tiny star had ceased its twinkling. Viewed simply as a star, the sun must retire to a position of insignificance in the mighty fabric[Pg 33] of the universe. But it is not as a star that we have to deal with the sun. To us his comparative proximity gives him an importance incalculably transcending that of all the other stars. We imagined ourselves to be withdrawn from the sun to obtain his true perspective in the universe; let us now draw near, and give him that attention which his supreme importance to us merits.

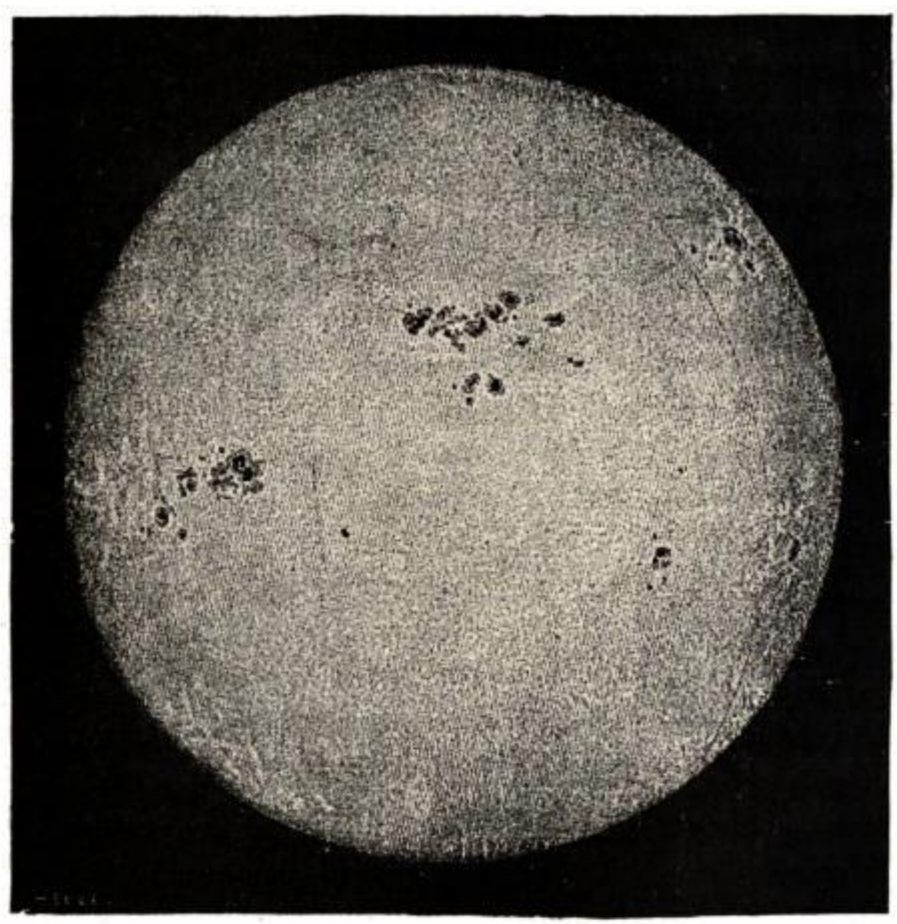

Fig. 11.—The Sun, photographed on September 22, 1870.

To the unaided eye the sun appears to be a flat circle. If, however, it be examined with the telescope, taking care of course to interpose a piece of dark-coloured glass, or to employ some similar precaution to screen the eye from injury, it will then be perceived that the sun is not a flat surface, but a veritable glowing globe.

The first question which we must attempt to answer[Pg 34] enquires whether the glowing matter which forms the globe is a solid mass, or, if not solid, which is it, liquid or gaseous? At the first glance we might think that the sun cannot be fluid, and we might naturally imagine that it was a solid ball of some white-hot substance. But this view is not correct; for we can show that the sun is certainly not a solid body in so far at least as its superficial parts are concerned.

A general view of the sun as shown by a telescope of moderate dimensions may be seen in Fig. 11, which is taken from a photograph obtained by Mr. Rutherford at New York on the 22nd of September, 1870. It is at once seen that the surface of the luminary is by no means of uniform texture or brightness. It may rather be described as granulated or mottled. This appearance is due to the luminous clouds which float suspended in a somewhat less luminous layer of gas. It is needless to say that these solar clouds are very different from the clouds which we know so well in our own atmosphere. Terrestrial clouds are, of course, formed from minute drops of water, while the clouds at the surface of the sun are composed of drops of one or more chemical elements at an exceedingly high temperature.

The granulated appearance of the solar surface is beautifully shown in the remarkable photographs on a large scale which M. Janssen, of Meudon, has succeeded in obtaining during the last twenty years. We are enabled to reproduce one of them in Fig. 12. It will be observed that the interstices between the luminous dots are of a greyish tint, the general effect (as remarked by Professor Young) being much like that of rough drawing paper seen from a little distance. We often notice places over the surface of such a plate where the definition seems to be unsatisfactory. These are not, however, the blemishes that might at first be supposed. They arise neither from casual imperfections of the photographic plate nor from accidents during the development; they plainly owe their origin to some veritable cause in the sun itself, nor shall we find it hard to explain what that cause must be. As we shall have occasion to mention further on, the velocities with which the glowing gases on the sun are animated must be exceedingly great. Even in the hundredth part of a second (which is about the duration of the exposure of this plate) the movements of the solar clouds are sufficiently great to produce the observed indistinctness.

[Pg 35]

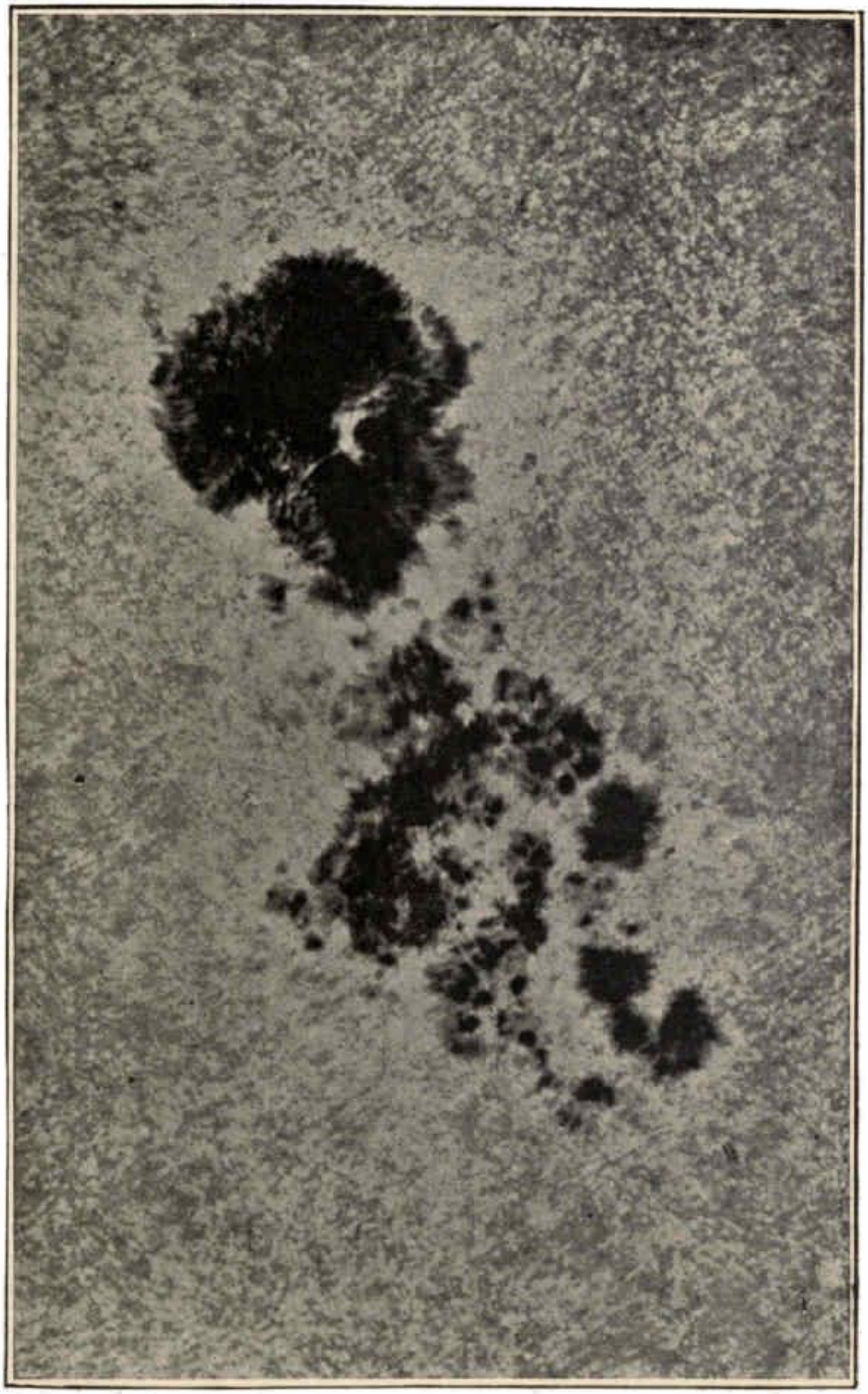

Fig.

12.—Photograph of the Solar Surface.
(*By Janssen.*)

[Pg 36]

Irregularly dispersed over the solar surface small dark objects called sun-spots are generally visible. These spots vary greatly both as to size and as to number. Sun-spots were first noticed in the beginning of the seventeenth century, shortly after the invention of the telescope. Their general appearance is shown in Fig. 13, in which the dark central nucleus appears in sharp contrast with the lighter margin or penumbra. Fig. 16 shows a small spot developing out of one of the pores or interstices between the granules.


Fig. 13.—An Ordinary Sun-spot.

The earliest observers of these spots had remarked that they seem to have a common motion across the sun. In Fig. 14 we give a copy of a remarkable drawing by Father Scheiner, showing the motion of two spots observed by him in March, 1627. The figure indicates the successive positions assumed by the spots on the several days from the 2nd to the 16th March. Those marks which are merely given in outline represent the assumed positions on the 11th and the 13th, on which days it happened that the weather was cloudy, so that no observations could be made. It is invariably found that these objects move in the same direction—namely, from the eastern to the western limb[3] of the sun. They complete the journey across the face of the sun in twelve or thirteen days, after which they remain invisible for about the same length of time until they reappear at the eastern limb. These early observers were quick to discern the true import of their discovery. They deduced from these simple observations the remarkable fact that the sun, like the earth, performs a rotation on its axis, and in the same direction. But there is the important difference between these rotations that whereas the earth takes only twenty-four hours to turn once round, the solar globe takes about twenty-six days to complete one of its much more deliberate rotations.

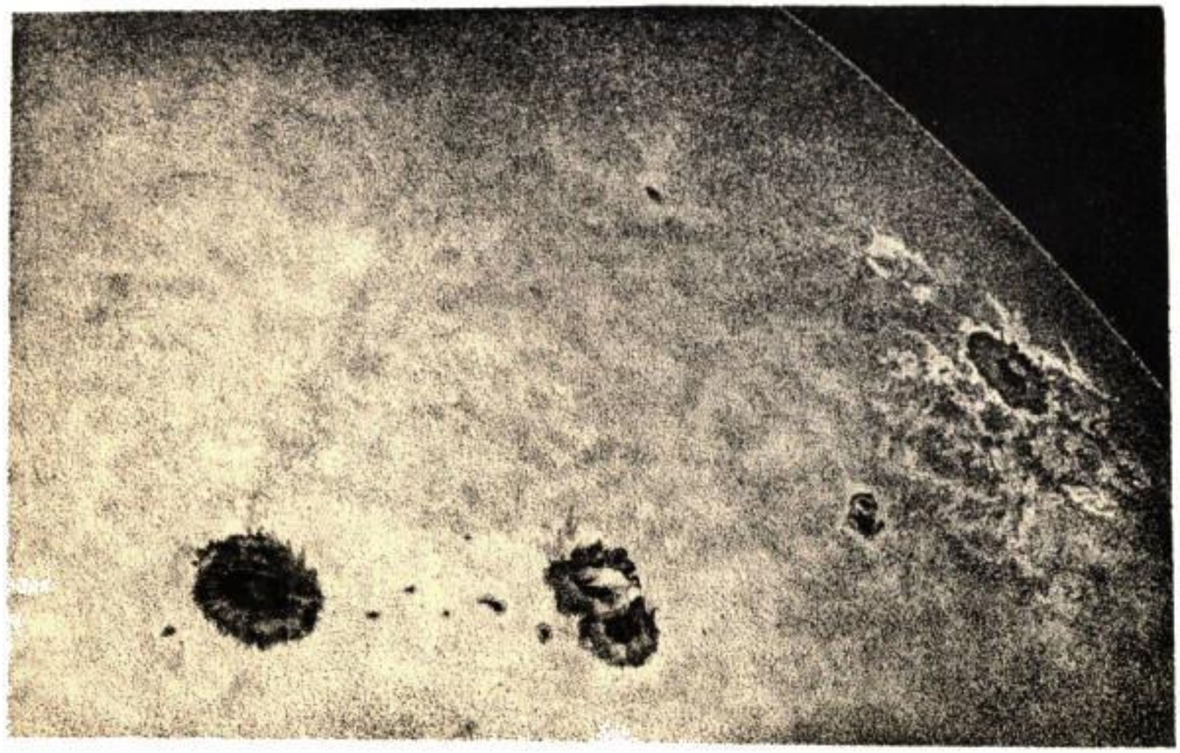

PLATE III.
SPOTS AND FACULÆ ON THE SUN.
(FROM A PHOTOGRAPH BY MR. WARREN DE LA RUE, 20TH SEPT., 1861.)

If we examine sun-spots under favourable atmospheric conditions and with a telescope of fairly large aperture, we perceive a great amount of interesting detail which is full of information with regard to the structure of the sun. The penumbra of a spot is often found to be made up of filaments directed towards the middle of the spot, and generally brighter at their inner ends, where they adjoin the nucleus. In a regularly formed spot the outline of the penumbra is of the same general form as that of the nucleus, but astronomers are frequently deeply interested by witnessing vast spots of very irregular figure. In such cases the bright surface-covering of the sun (the photosphere, as it is called) often encroaches on the nucleus and forms a peninsula stretching out into, or even bridging across, the gloomy interior. This is well shown in Professor Langley's fine drawing (Plate II.) of a very irregular spot which he observed on December 23–24, 1873.

The details of a spot vary continually; changes may often be noticed even from day to day, sometimes from hour to hour. A similar remark may be made with respect to the bright streaks or patches which are frequently to be observed especially in the neighbourhood of spots. These bright marks are known by the name of *faculæ* (little torches). They are most distinctly seen near the margin of the sun, where the light from its surface is not so bright as it is nearer to the centre of the disc. The reduction of light at the margin is due to the greater thickness of absorbing atmosphere round the sun, through which the light emitted from the regions near the margin has to pass in starting on its way towards us.

None of the markings on the solar disc constitute permanent features on the sun. Some of these objects may no doubt last for weeks. It has, indeed, occasionally happened that the same spot has marked the solar globe for many months; but after an existence of greater or less duration those on one part of the sun may disappear, while as frequently fresh marks of the same kind become visible in other places. The inference from these various facts is[Pg 38] irresistible. They tell us that the visible surface of the sun is not a solid mass, is not even a liquid mass, but that the globe, so far as we can see it, consists of matter in the gaseous, or vaporous, condition.

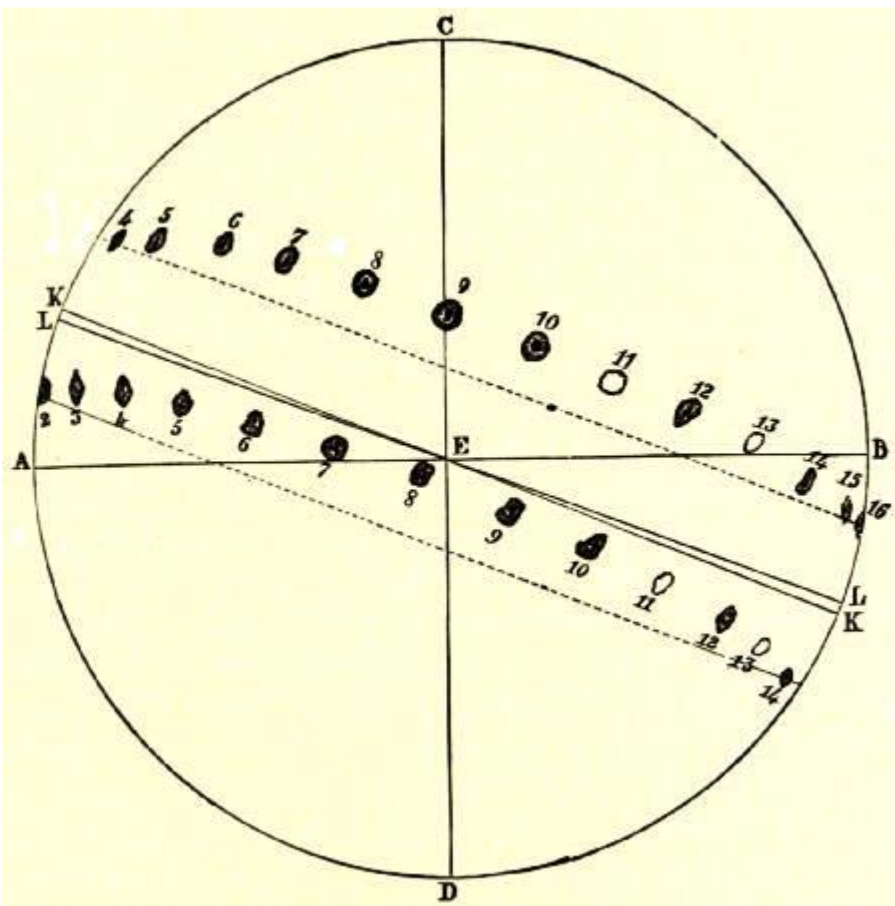

Fig. 14.—Scheiner's Observations on Sun-spots.

It often happens that a large spot divides into two or more separate portions, and these have been sometimes seen to fly apart with a velocity in some cases not less than a thousand miles an hour. "At times, though very rarely" (I quote here Professor Young,[4] to whom I am frequently indebted), "a different phenomenon of the most surprising and startling character appears in connection with these objects: patches of intense brightness suddenly break out, remaining visible for a few minutes, moving, while they[Pg 39] last, with velocities as great as one hundred miles *a second*."

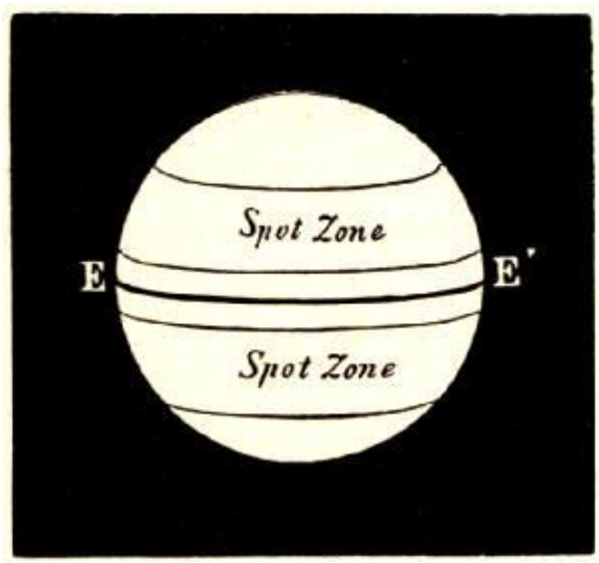

Fig. 15.—Zones on the Sun's Surface in which Spots appear.

"One of these events has become classical. It occurred on the forenoon (Greenwich time) of September 1st, 1859, and was independently witnessed by two well-known and reliable observers—Mr. Carrington and Mr. Hodgson—whose accounts of the matter may be found in the Monthly Notices of the Royal Astronomical Society for November, 1859. Mr. Carrington at the time was making his usual daily observations upon the position, configuration, and size of the spots by means of an image of the solar disc upon a screen—being then engaged upon that eight years' series of observations which lie at the foundation of so much of our present solar science. Mr. Hodgson, at a distance of many miles, was at the same time sketching details of sun-spot structure by means of a solar eye-piece and shade-glass. They simultaneously saw two luminous objects, shaped something like two new moons, each about eight thousand miles in length and two thousand wide, at a distance of some twelve thousand miles from each other. These burst suddenly into sight at the edge of a great sun-spot with a dazzling brightness at least five or six times that of the neighbouring portions of the photosphere, and moved eastward over the spot in parallel lines, growing smaller and fainter, until in about five minutes they disappeared, after traversing a course of nearly thirty-six thousand miles."

The sun-spots do not occur at all parts of the sun's surface indifferently. They are mainly found in two zones (Fig. 15) on each side of the solar equator between the latitudes of 10° and 30°. On the equator the spots are rare except, curiously enough, near the time when there are few spots elsewhere. In high latitudes they are never seen. Closely connected with these peculiar principles of their distribution[Pg 40] is the remarkable fact that spots in different latitudes do not indicate the same values for the period of rotation of the sun. By watching a spot near the sun's equator Carrington found that it completed a revolution in twenty-five days and two hours. At a latitude of 20° the period is about twenty-five days and eighteen hours, at 30° it is no less than twenty-six days and twelve hours, while the comparatively few spots observed in the latitude of 45° require twenty-seven and a half days to complete their circuit.

As the sun, so far at least as its outer regions are concerned, is a mass of gas and not a solid body, there would be nothing incredible in the supposition that spots are occasionally endowed with movements of their own like ships on the ocean. It seems, however, from the facts before us that the different zones on the sun, corresponding to what we call the torrid and temperate zones on the earth, persist in rotating with velocities which gradually decrease from the equator towards the poles. It seems probable that the interior parts of the sun do not rotate as if the whole were a rigidly connected mass. The mass of the sun, or at all events its greater part, is quite unlike a rigid body, and the several portions are thus to some extent free for independent motion. Though we cannot actually see how the interior parts of the sun rotate, yet here the laws of dynamics enable us to infer that the interior layers of the sun rotate more rapidly than the outer layers, and thus some of the features of the spot movements can be accounted for. But at present it must be confessed that there are great difficulties in the way of accounting for the distribution of spots and the law of rotation of the sun.

In the year 1826 Schwabe, a German astronomer, commenced to keep a regular register of the number of spots visible on the sun. After watching them for seventeen years he was able to announce that the number of spots seemed to fluctuate from year to year, and that there was a period of about ten years in their changes. Subsequent observations have confirmed this discovery, and old books and manuscripts have been thoroughly searched for information of early date.[Pg 41] Thus a more or less complete record of the state of the sun as regards spots since the beginning of the seventeenth century has been put together. This has enabled astronomers to fix the period of the recurring maximum with greater accuracy.

The course of one of the sun-spot cycles may be described as follows: For two or three years the spots are both larger and more numerous than on the average; then they begin to diminish, until in about six or seven years from the maximum they decline to a minimum; the number of the spots then begins to increase, and in about four and a half years the maximum is once more attained. The length of the cycle is, on an average, about eleven years and five weeks, but both its length and the intensity of the maxima vary somewhat. For instance, a great maximum occurred in the summer of 1870, after which a very low minimum occurred in 1879, followed by a feeble maximum at the end of 1883; next came an average minimum about August, 1889, followed by the last observed maximum in January, 1894. It is not unlikely that a second period of about sixty or eighty years affects the regularity of the eleven-year period. Systematic observations carried on through a great many years to come will be required to settle this question, as the observations of sun-spots previous to 1826 are far too incomplete to decide the issues which arise.

A curious connection seems to exist between the periodicity of the spots and their distribution over the surface of the sun. When a minimum is about to pass away the spots generally begin to show themselves in latitudes about 30° north and south of the sun's equator; they then gradually break out somewhat nearer to the equator, so that at the time of maximum frequency most of them appear at latitudes not greater than 16°. This distance from the sun's equator goes on decreasing till the time of minimum. Indeed, the spots linger on very close to the equator for a couple of years more, until the outbreak signalising the commencement of another period has commenced in higher latitudes.

We have still to note an extraordinary feature which[Pg 42] points to an intimate connection between the phenomena of sun-spots and the purely terrestrial phenomena of magnetism. It is of course well known that the needle of a compass does not point exactly to the north, but diverges from the meridian by an angle which is different in different places and is not even constant at the same place. For instance, at Greenwich the needle at present points in a direction 17° West of North, but this amount is subject to very slow and gradual changes, as well as to very small daily oscillations. It was found about fifty years ago by Lamont (a Bavarian astronomer, but a native of Scotland) that the extent of this daily oscillation increases and decreases regularly in a period which he gave as 10-1⁄3 years, but which was subsequently found to be 11-1⁄10 years, exactly the same as the period of the spots on the sun. From a diligent study of the records of magnetic observations it has been found that the time of sun-spot maximum always coincides almost exactly with that of maximum daily oscillation of the compass needle, while the minima agree similarly.

This close relationship between the periodicity of sun-spots and the daily movements of the magnetic needle is not the sole proof we possess that there is a connection of some sort between solar phenomena and terrestrial magnetism. A time of maximum sun-spots is a time of great magnetic activity, and there have even been special cases in which a peculiar outbreak on the sun has been associated with remarkable magnetic phenomena on the earth. A very interesting instance of this kind is recorded by Professor Young, who, when observing at Sherman on the 3rd August, 1872, perceived a very violent disturbance of the sun's surface. He was told the same day by a member of his party, who was engaged in magnetic observations and who was quite in ignorance of what Professor Young had seen, that he had been obliged to desist from his magnetic work in consequence of the violent motion of his magnet. It was afterwards found from the photographic records at Greenwich and Stonyhurst that the magnetic "storm" observed in America had simultaneously been felt in England. A similar connection between sun-spots and the aurora borealis has[Pg 43] also been noticed, this fact being a natural consequence of the well-known connection between the aurora and magnetic disturbances. On the other hand, it must be confessed that many striking magnetic storms have occurred without any corresponding solar disturbance,[5] but even those who are inclined to be sceptical as to the connection between these two classes of phenomena in particular cases can hardly doubt the remarkable parallelism between the general rise and fall in the number of sun-spots and the extent of the daily movements of the compass needle.

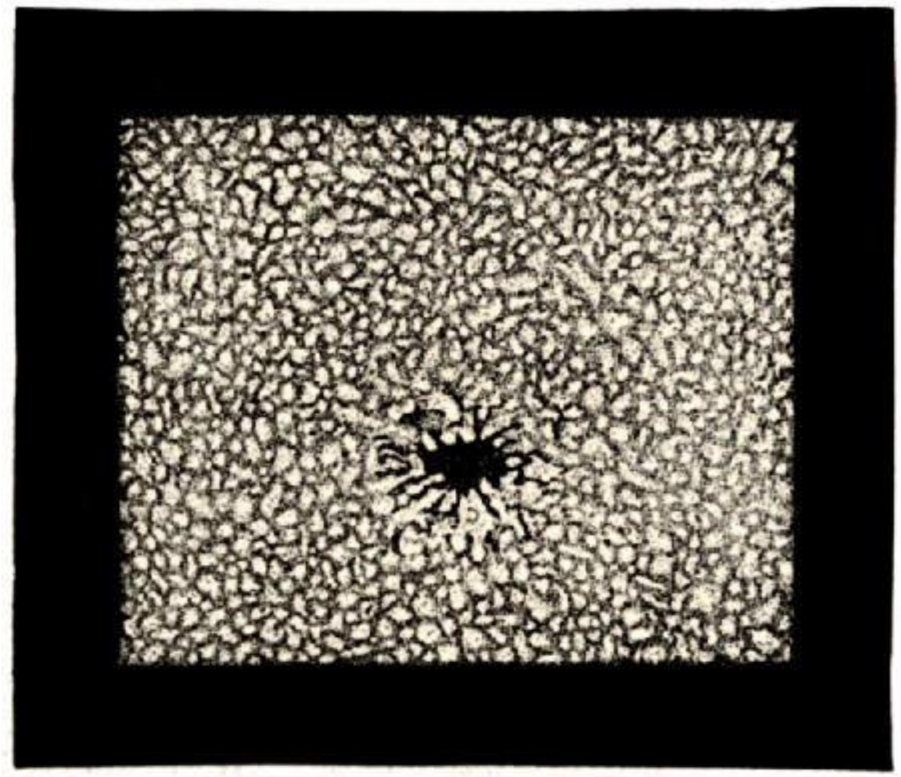
Fig. 16.—The Texture of the Sun and a small Spot.

We have now described the principal solar phenomena with which the telescope has made us acquainted. But there are many questions connected with the nature of the sun which not even the most powerful telescope would enable us to solve, but which the spectroscope has given us the means of investigating.

What we receive from the sun is warmth and light. The intensely heated mass of the sun radiates forth its beams in[Pg 44] all directions with boundless prodigality. Each beam we feel to be warm, and we see to be brilliantly white, but a more subtle analysis than mere feeling or mere vision is required. Each sunbeam bears marks of its origin. These marks are not visible until a special process has been applied, but then the sunbeam can be made to tell its story, and it will disclose to us much of the nature of the constitution of the great luminary.

We regard the sun's light as colourless, just as we speak of water as tasteless, but both of those expressions relate rather to our own feelings than to anything really characteristic of water or of sunlight. We regard the sunlight as colourless because it forms, as it were, the background on which all other colours are depicted. The fact is, that white is so far from being colourless that it contains every known hue blended together in certain proportions. The sun's light is really extremely composite; Nature herself tells us this if we will but give her the slightest attention. Whence come the beautiful hues with which we are all familiar? Look at the lovely tints of a garden; the red of the rose is not in the rose itself. All the rose does is to grasp the sunbeams which fall upon it, extract from these beams the red which they contain, and radiate that red light to our eyes. Were there not red rays conveyed with the other rays in the sunbeam, there could be no red rose to be seen by sunlight.

The principle here involved has many other applications; a lady will often say that a dress which looks very well in the daylight does not answer in the evening. The reason is that the dress is intended to show certain colours which exist in the sunlight; but these colours are not contained to the same degree in gaslight, and consequently the dress has a different hue. The fault is not in the dress, the fault lies in the gas; and when the electric light is used it sends forth beams more nearly resembling those from the sun, and the colours of the dress appear with all their intended beauty.

The most glorious natural indication of the nature of the sunlight is seen in the rainbow. Here the sunbeams are refracted and reflected from tiny globes of water in the clouds; these convey to us the sunlight, and in doing so decompose the white beams into the seven primary hues—red, orange, yellow, green, blue, indigo, and violet.

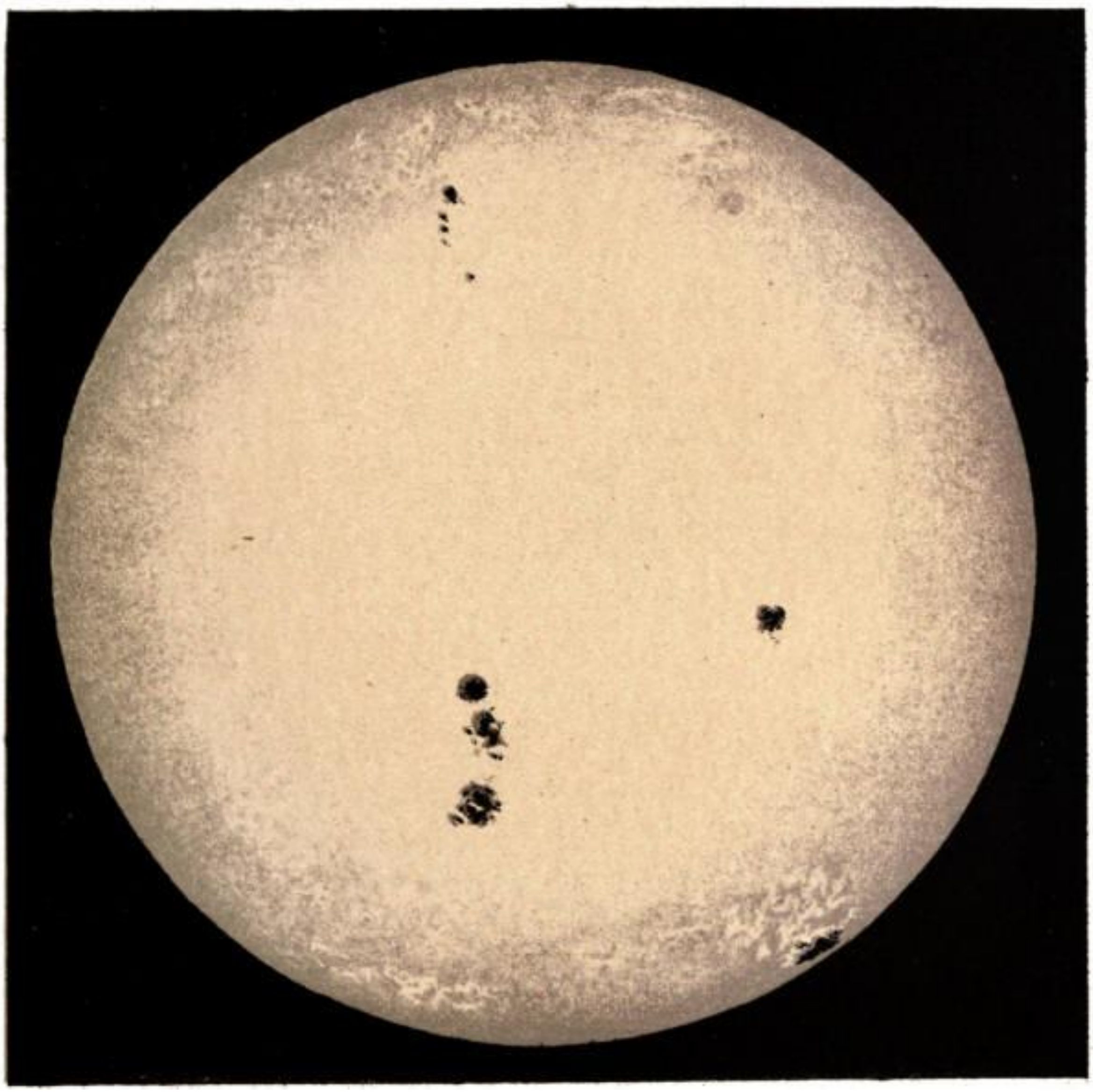

PLATE A.
THE SUN.
Royal Observatory, Greenwich, July 8, 1892.

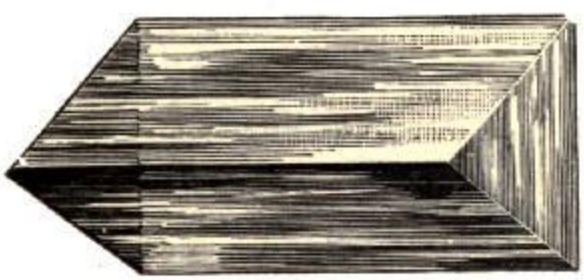

Fig. 17.—The Prism.

The bow set in the cloud is typical of that great department of modern science of which we shall now set forth the principles. The globes of water decompose the solar beams; and we follow the course suggested by the rainbow, and analyse the sunlight into its constituents. We are enabled to do this with scientific accuracy when we employ that remarkable key to Nature's secrets known as the spectroscope. The beams of white sunlight consist of innumerable beams of every hue in intimate association. Every shade of red, of yellow, of blue, and of green, can be found in a sunbeam. The magician's wand, with which we strike the sunbeam and sort the tangled skein into perfect order, is the simple instrument known as the glass prism. We have represented this instrument in its simplest form in the adjoining figure (Fig. 17). It is a piece of pure and homogeneous glass in the shape of a wedge. When a ray of light from the sun or from any source falls upon the prism, it passes through the transparent glass and emerges on the other side; a remarkable change is, however, impressed on the ray by the influence of the glass. It is bent by refraction from the path it originally pursued, and is compelled to follow a different path. If, however, the prism bent all rays of light equally, then it would be of no service in the analysis of light; but it fortunately happens that the prism acts with varying efficiency on the rays of different hues. A red ray is not refracted so much as a yellow ray; a yellow ray is not refracted so much as a blue one. It consequently happens that when the composite beam of sunlight, in which all the different rays are blended, passes through the prism, they emerge in the manner shown in the annexed figure (Fig. 18). Here then we have the source of the analysing[Pg 46] power of the prism; it bends the different hues unequally and consequently the beam of composite sunlight, after passing through the prism, no longer shows mere white light, but is expanded into a coloured band of light, with hues like the rainbow, passing from deep red at one end through every intermediate grade to the violet.

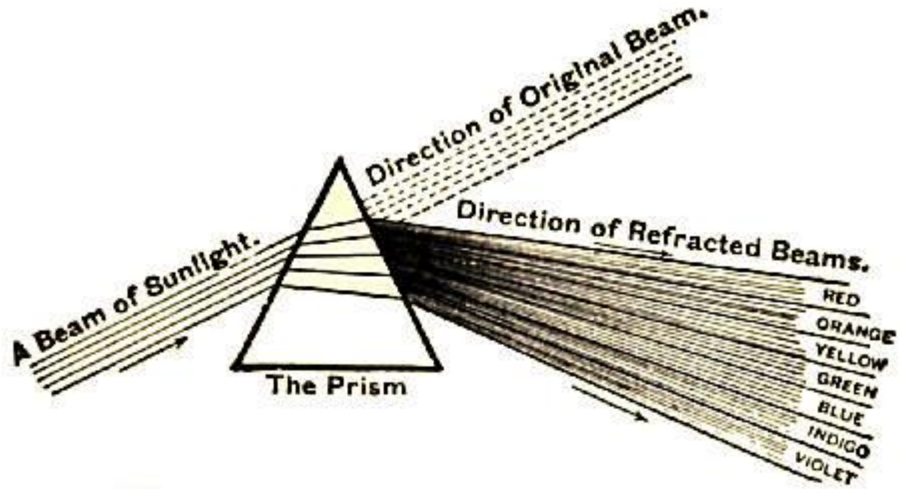

Fig. 18.—Dispersion of Light by the Prism.

We have in the prism the means of decomposing the light from the sun, or the light from any other source, into its component parts. The examination of the quality of the light when analysed enables us to learn something of the constitution of the body from which this light has emanated. Indeed, in some simple cases the mere colour of a light will be sufficient to indicate the source from which it has come. There is, for instance, a splendid red light sometimes seen in displays of fireworks, due to the metal strontium. The eye can identify the element by the mere colour of the flame. There is also a characteristic yellow light produced by the flame of common salt burned with spirits of wine. Sodium is the important constituent of salt, so here we recognise another substance merely by the colour it emits when burning. We may also mention a third substance, magnesium, which burns with a brilliant white light, eminently characteristic of the metal.

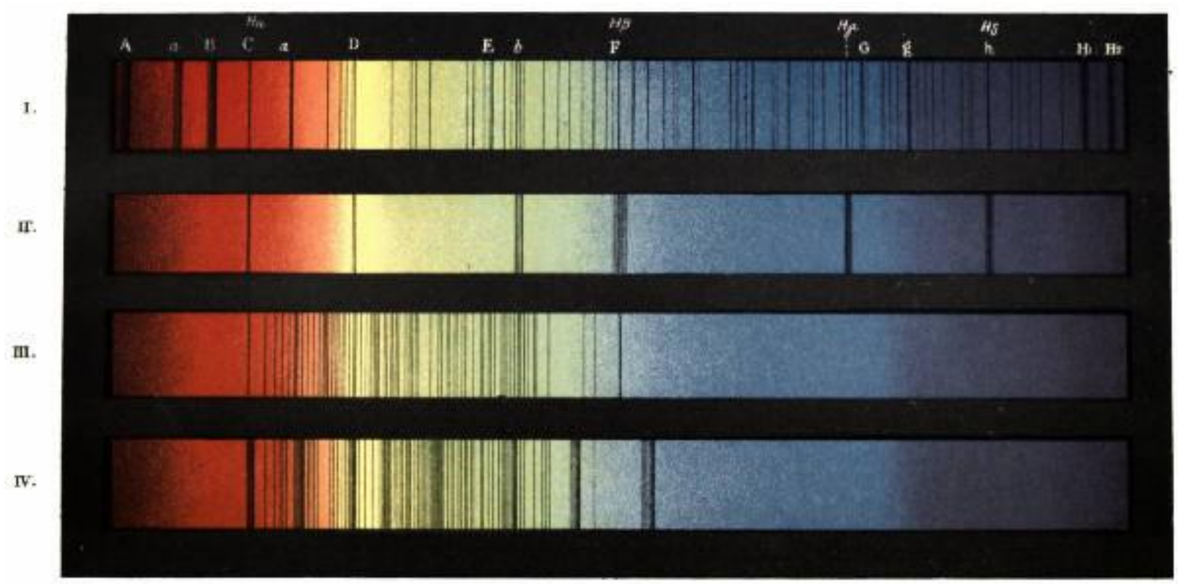

PLATE XIII.
SPECTRA OF THE SUN AND STARS.
I. SUN.
II. SIRIUS.
III. ALDEBARAN.
IV. BETELGEUZE.

The three metals, strontium, sodium, and magnesium, may thus be identified by the colours they produce when incandescent. In this simple observation lies the germ of the modern method of research known as spectrum analysis. We may now examine with the prism the colours of the sun and the colours of the stars, and from this examination we can learn something of the materials which enter into their composition. We are not restricted to the use of merely a single prism, but we may arrange that the light which it is desired to analyse shall pass through several prisms in succession in order to increase the *dispersion* or the spreading out of the different colours. To enter the spectroscope the light first passes through a narrow slit, and the rays are then rendered parallel by passing through a lens; these parallel rays next pass through one or more prisms, and are finally viewed through a small telescope, or they may be intercepted by a photographic plate on which a picture will then be made. If the beam of light passing through the slit has radiated from an incandescent solid or liquid body, or from a gas under high pressure, the coloured band or *spectrum* is found to contain all the colours indicated on Plate XIII., without any interruption between the colours. This is known as a continuous spectrum. But if we examine light from a gas under low pressure, as can be done by placing a small quantity of the gas in a glass tube and making it glow by an electric current, we find that it does not emit rays of all colours, but only rays of certain distinct colours which are different for different gases. The spectrum of a gas, therefore, consists of a number of detached luminous lines.

When we study the sunlight through the prism, it is found that the spectrum does not extend quite continuously from one end to the other, but is shaded over by a multitude of dark lines, only a few of which are shown in the adjoining plate. (Plate XIII.) These lines are a permanent feature in the solar spectrum. They are as characteristic of the sunlight as the prismatic colours themselves, and are full of interest and information with regard to the sun. These lines are the characters in which the history and the nature of the sun are written. Viewed through an instrument of adequate power, dark lines are to be found crossing the solar spectrum[Pg 48] in hundreds and in thousands. They are of every variety of strength and faintness; their distribution seems guided by no simple law. At some parts of the spectrum there are but few lines; in other regions they are crowded so closely together that it is difficult to separate them. They are in some places exquisitely fine and delicate, and they never fail to excite the admiration of every one who looks at this interesting spectacle in a good instrument.

There can be no better method of expounding the rather difficult subject of spectrum analysis than by actually following the steps of the original discovery which first gave a clear demonstration of the significance of the dark "Fraunhofer" lines. Let us concentrate our attention specially upon that line of the solar spectrum marked D. This, when seen in the spectroscope, is found to consist of two lines, very delicately separated by a minute interval, one of these lines being slightly thicker than the other. Suppose that while the attention is concentrated on these lines the flame of an ordinary spirit-lamp coloured by common salt be held in front of the instrument, so that the ray of direct solar light passes through the flame before entering the spectroscope. The observer sees at once the two lines known as D flash out with a greatly increased blackness and vividness, while there is no other perceptible effect on the spectrum. A few trials show that this intensification of the D lines is due to the vapour of sodium arising from the salt burning in the lamp through which the sunlight has passed.

It is quite impossible that this marvellous connection between sodium and the D lines of the spectrum can be merely casual. Even if there were only a single line concerned, it would be in the highest degree unlikely that the coincidence should arise by accident; but when we find the sodium affecting both of the two close lines which form D, our conviction that there must be some profound connection between these lines and sodium rises to absolute certainty. Suppose that the sunlight be cut off, and that all other light is excluded save that emanating from the glowing vapour of[Pg 49] sodium in the spirit flame. We shall then find, on looking through the spectroscope, that we no longer obtain all the colours of the rainbow; the light from the sodium is concentrated into two bright yellow lines, filling precisely the position which the dark D lines occupied in the solar spectrum, and the darkness of which the sodium flame seemed to intensify.

We must here endeavour to remove what may at first sight appear to be a paradox. How is it, that though the sodium flame produces two *bright* lines when viewed in the absence of other light, yet it actually appears to intensify the two *dark* lines in the sun's spectrum? The explanation of this leads us at once to the cardinal doctrine of spectrum analysis. The so-called dark lines in the solar spectrum are only dark *by contrast* with the brilliant illumination of the rest of the spectrum. A good deal of solar light really lies in the dark lines, though not enough to be seen when the eye is dazzled by the brilliancy around. When the flame of the spirit-lamp charged with sodium intervenes, it sends out a certain amount of light, which is entirely localised in these two lines. So far it would seem that the influence of the sodium flame ought to be manifested in diminishing the darkness of the lines and rendering them less conspicuous. As a matter of fact, they are far more conspicuous with the sodium flame than without it. This arises from the fact that the sodium flame possesses the remarkable property of cutting off the sunlight which was on its way to those particular lines; so that, though the sodium contributes some light to the lines, yet it intercepts a far greater quantity of the light that would otherwise have illuminated those lines, and hence they became darker with the sodium flame than without it.

We are thus conducted to a remarkable principle, which has led to the interpretation of the dark lines in the spectrum of the sun. We find that when the sodium vapour is heated, it gives out light of a very particular type, which, viewed through the prism, is concentrated in two lines. But the sodium vapour possesses also this property, that light from[Pg 50] the sun can pass through it without any perceptible absorption, except of those particular rays which are of the same characters as the two lines in question. In other words, we say that if the heated vapour of a substance gives a spectrum of bright lines, corresponding to lights of various kinds, this same vapour will act as an opaque screen to lights of those special kinds, while remaining transparent to light of every other description.

This principle is of such importance in the theory of spectrum analysis that we add a further example. Let us take the element iron, which in a very striking degree illustrates the law in question. In the solar spectrum some hundreds of the dark lines are known to correspond with the spectrum of iron. This correspondence is exhibited in a vivid manner when, by a suitable contrivance, the light of an electric spark from poles of iron is examined in the spectroscope side by side with the solar spectrum. The iron lines in the sun are identical in position with the lines in the spectrum of glowing iron vapour. But the spectrum of iron, as here described, consists of bright lines; while those with which it is compared in the sun are dark on a bright background. They can be completely understood if we suppose the vapour arising from intensely heated iron to be present in the atmosphere which surrounds the luminous strata on the sun. This vapour would absorb or stop precisely the same rays as it emits when incandescent, and hence we learn the important fact that iron, no less than sodium, must, in one form or another, be a constituent of the sun.

Such is, in brief outline, the celebrated discovery of modern times which has given an interpretation to the dark lines of the solar spectrum. The spectra of a large number of terrestrial substances have been examined in comparison with the solar spectrum, and thus it has been established that many of the elements known on the earth are present in the sun. We may mention calcium, iron, hydrogen, sodium, carbon, nickel, magnesium, cobalt, aluminium, chromium, strontium, manganese, copper, zinc, cadmium, silver, tin, lead, potassium. Some of the elements which are of the greatest importance[Pg 51] on the earth would appear to be missing from the sun. Sulphur, phosphorus, mercury, gold, nitrogen may be mentioned among the elements which have hitherto given no indication of their being solar constituents.

It is also possible that the lines of a substance in the sun's atmosphere may be so very bright that the light of the continuous spectrum, on which they are superposed, is not able to "reverse" them—*i.e.* turn them into dark lines. We know, for instance, that the bright lines of sodium vapour may be made so intensely bright that the spectrum of an incandescent lime-cylinder placed behind the sodium vapour does not reverse these lines. If, then, we make the sodium lines fainter, they may be reduced to exactly the intensity prevailing in that part of the spectrum of the lime-light, in which case the lines, of course, could not be distinguished. The question as to what elements are really missing from the sun must therefore, like many other questions concerning our great luminary, at present be considered an open one. We shall shortly see that an element previously unknown has actually been discovered by means of a line representing it in the solar spectrum.

Let us now return to the sun-spots and see what the spectroscope can teach us as to their nature. We attach a powerful spectroscope to the eye-end of a telescope in order to get as much light as possible concentrated on the slit; the latter has therefore to be placed exactly at the focus of the object-glass. The instrument is then pointed to a spot, so that its image falls on the slit, and the presence of the dark central part called the *umbra* reveals itself by a darkish stripe which traverses the ordinary sun-spectrum from end to end. It is bordered on both sides by the spectrum of the *penumbra*, which is much brighter than that of the umbra, but fainter than that of the adjoining regions of the sun.

From the fact that the spectrum is darkened we learn that there is considerable general absorption of light in the umbra. This absorption is not, however, such as would be caused by the presence of volumes of minute solid or liquid particles like those which constitute smoke or cloud. This is indicated[Pg 52] by the fact, first discovered by Young in 1883, that the spectrum is not uniformly darkened as it would be if the absorption were caused by floating particles. In the course of examination of many large and quiescent spots, he perceived that the middle green part of the spectrum was crossed by countless fine, dark lines, generally touching each other, but here and there separated by bright intervals. Each line is thicker in the middle (corresponding to the centre of the spot) and tapers to a fine thread at each end; indeed, most of these lines can be traced across the spectrum of the penumbra and out on to that of the solar surface. The absorption would therefore seem to be caused by gases at a much lower temperature than that of the gases present outside the spot.

In the red and yellow parts of the spot-spectrum, which have been specially studied for many years by Sir Norman Lockyer at the South Kensington Observatory, interesting details are found which confirm this conclusion. Many of the dark lines are not thicker and darker in the spot than they are in the ordinary sun-spectrum, while others are very much thickened in the spot-spectrum, such as the lines of iron, calcium, and sodium. The sodium lines are sometimes both widened and doubly reversed—that is, on the thick dark line a bright line is superposed. The same peculiarity is not seldom seen in the notable calcium lines H and K at the violet end of the spectrum. These facts indicate the presence of great masses of the vapours of sodium and calcium over the nucleus. The observations at South Kensington have also brought to light another interesting peculiarity of the spot-spectra. At the time of minimum frequency of spots the lines of iron and other terrestrial elements are prominent among the most widened lines; at the maxima these almost vanish, and the widening is found only amongst lines of unknown origin.

The spectroscope has given us the means of studying other interesting features on the sun, which are so faint that in the full blaze of sunlight they cannot be readily observed with a mere telescope. We can, however, see them easily enough when the brilliant body of the sun is obscured during the rare occurrence of a total eclipse. The conditions necessary[Pg 53] for the occurrence of an eclipse will be more fully considered in the next chapter. For the present it will be sufficient to observe that by the movement of the moon it may so happen that the moon completely hides the sun, and thus for certain parts of the earth produces what we call a total eclipse. The few minutes during which a total eclipse lasts are of much interest to the astronomer. Darkness reigns over the landscape, and in that darkness rare and beautiful sights are witnessed.

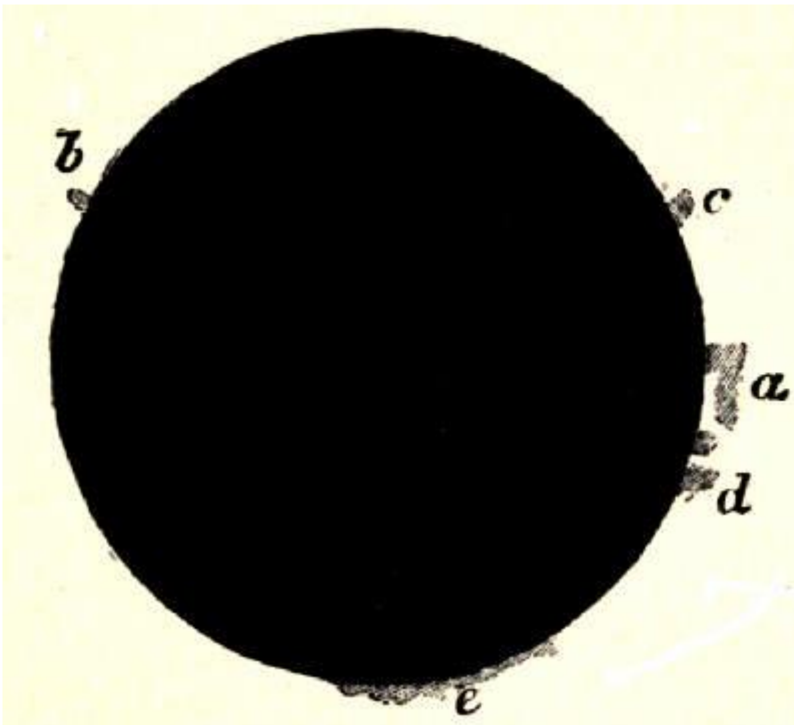

Fig. 19.—Prominences seen in Total Eclipse.

We have in Fig. 19 a diagram of a total eclipse, showing some of the remarkable objects known as prominences (*a*, *b*, *c*, *d*, *e*) which project from behind the dark body of the moon. That they do not belong to the moon, but are solar appendages of some sort, is easily demonstrated. They first appear on the eastern limb at the commencement of totality. Those first seen are gradually more or less covered by the advancing moon, while others peep out behind the western limb of the moon, until totality is over and the sunlight bursts out again, when they all instantly vanish.

The first total eclipse which occurred after the spectroscope had been placed in the hands of astronomers was in 1868. On the 18th August in that year a total eclipse was visible in India. Several observers, armed with spectroscopes, were on the look-out for the prominences, and were able to announce that their spectrum consisted of detached bright lines, thus demonstrating that these objects were masses of glowing gas. On the following day the illustrious astronomer, Janssen, one of the observers of the eclipse, succeeded in seeing the lines in full sunlight, as he now knew exactly where to look for them. Many months before the eclipse Sir Norman Lockyer had been preparing to search for the prominences, as he expected them to yield[Pg 54] a line spectrum which would be readily visible, if only the sun's ordinary light could be sufficiently winnowed away. He proposed to effect this by using a spectroscope of great dispersion, which would spread out the continuous spectrum considerably and make it fainter. The effect of the great dispersion on the isolated bright lines he expected to see would be only to widen the intervals between them without interfering with their brightness. The new spectroscope, which he ordered to be constructed for this purpose, was not completed until some weeks after the eclipse was over, though before the news of Janssen's achievement reached Europe from India. When that news did arrive Sir N. Lockyer had already found the spectrum of unseen prominences at the sun's limb. The honour of the practical application of a method of observing solar prominences without the help of an eclipse must therefore be shared between the two astronomers.

When a spectroscope is pointed to the margin of the sun so that the slit is radial, certain short luminous lines become visible which lie exactly in the prolongation of the corresponding dark lines in the solar spectrum. From due consideration of the circumstances it can be shown that the gases which form the prominences are also present as a comparatively shallow atmospheric layer all round the great luminary. This layer is about five or six thousand miles deep, and is situated immediately above the dense layer of luminous clouds which forms the visible surface of the sun and which we call the photosphere. The gaseous envelope from which the prominences spring has been called the chromosphere on account of the coloured lines displayed in its spectrum. Such lines are very numerous, but those pertaining to the single substance, hydrogen, predominate so greatly that we may say the chromosphere consists chiefly of this element. It is, however, to be noted that calcium and one other element are also invariably present, while iron, manganese and magnesium are often apparent. The remarkable element, of which we have not yet mentioned the name, has had an astonishing history.

[Pg 55]

During the eclipse of 1868 a fine yellow line was noticed among the lines of the prominence spectrum, and it was not unnaturally at first assumed that it must be the yellow sodium line. But when careful observations were afterwards made without hurry in full sunshine, and accurate measures were obtained, it was at once remarked that this line was not identical with either of the components of the double sodium line. The new line was, no doubt, quite close to the sodium lines, but slightly towards the green part of the spectrum. It was also noticed there was not generally any corresponding line to be seen among the dark lines in the ordinary solar spectrum, though a fine dark one has now and then been detected, especially near a sun-spot. Sir Norman Lockyer and Sir Edward Frankland showed that this was not produced by any known terrestrial element. It was, therefore, supposed to be caused by some hitherto unknown body to which the name of *helium*, or the sun element, was given. About a dozen less conspicuous lines were gradually identified in the spectrum of the prominences and the chromosphere, which appeared also to be caused by this same mysterious helium. These same remarkable lines have in more recent years also been detected in the spectra of various stars.

This gas so long known in the heavens was at last detected on earth. In April, 1895, Professor Ramsay, who with Lord Rayleigh had discovered the new element argon, detected the presence of the famous helium line in the spectrum of the gas liberated by heating the rare mineral known as cleveite, found in Norway. Thus this element, the existence of which had first been detected on the sun, ninety-three million miles away, has at last been proved to be a terrestrial element also.

When it was announced by Runge that the principal line in the spectrum of the terrestrial helium had a faint and very close companion line on the red-ward side, some doubt seemed at first to be cast on the identity of the new terrestrial gas discovered by Ramsay with the helium of the chromosphere. The helium line of the latter had never been noticed to be double. Subsequently, however, several observers provided[Pg 56] with very powerful instruments found that the famous line in the chromosphere really had a very faint companion line. Thus the identity between the celestial helium and the gas found on our globe was established in the most remarkable manner. Certain circumstances have seemed to indicate that the new gas might possibly be a mixture of two gases of different densities, but up to the present this has not been proved to be the case.

After it had been found possible to see the spectra of prominences without waiting for an eclipse, Sir W. Huggins, in an observation on the 13th of February, 1869, successfully applied a method for viewing the remarkable solar objects themselves instead of their mere spectra in full sunshine. It is only necessary to adjust the spectroscope so that one of the brightest lines—*e.g.* the red hydrogen line—is in the middle of the field of the viewing telescope, and then to open wide the slit of the spectroscope. A red image of the prominence will then be displayed instead of the mere line. In fact, when the slit is opened wide, the prisms produce a series of detached images of the prominence under observation, one for each kind of light which the object emits.

We have spoken of the spectroscope as depending upon the action of glass prisms. It remains to be added that in the highest class of spectroscopes the prisms are replaced by ruled gratings from which the light is reflected. The effect of the ruling is to produce by what is known as diffraction the required breaking up of the beam of light into its constituent parts.

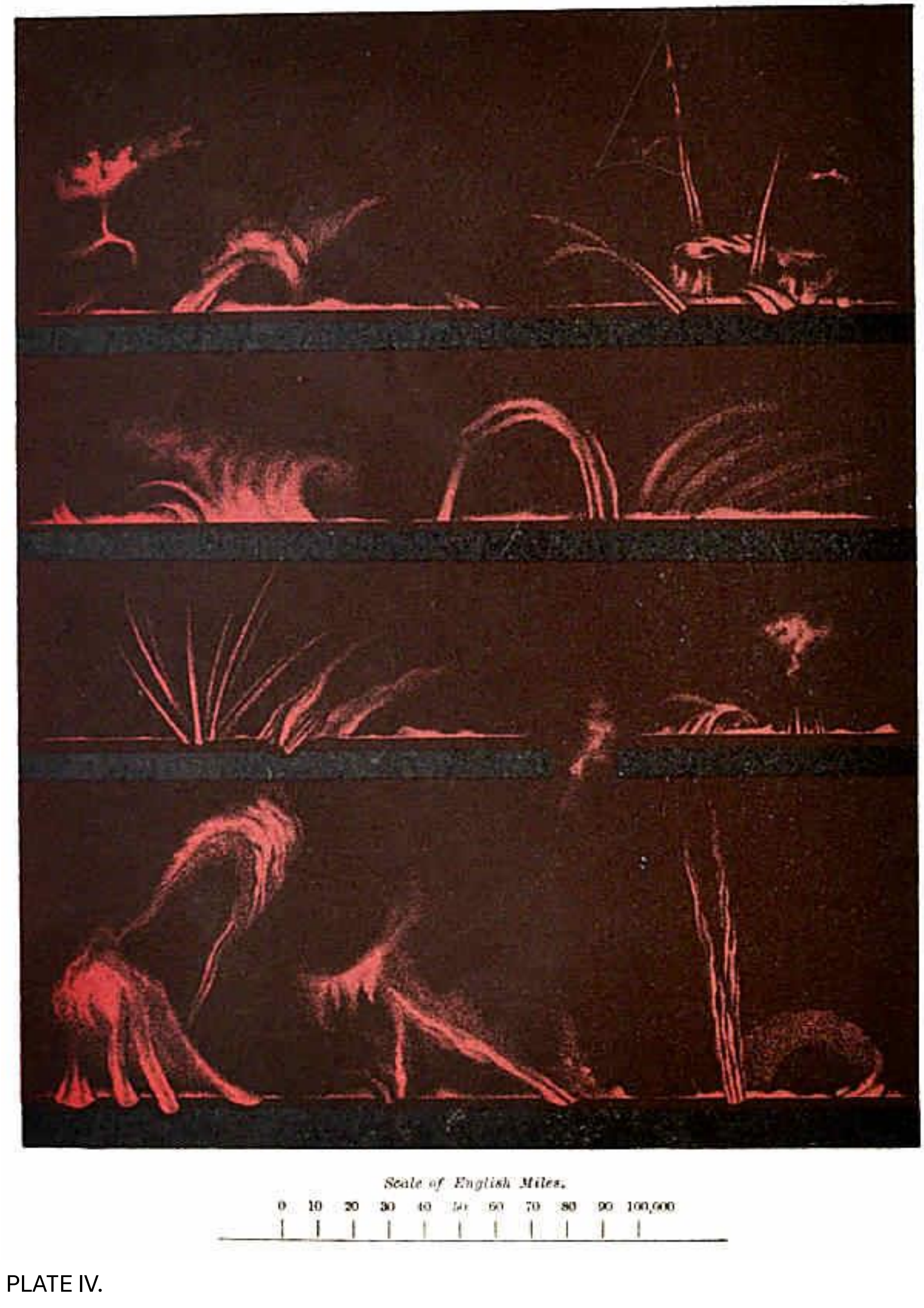

PLATE IV.

SOLAR PROMINENCES.
(DRAWN BY TROUVELOT AT HARVARD COLLEGE, CAMBRIDGE, U.S., IN 1872.)

Majestic indeed are the proportions of some of those mighty prominences which leap from the luminous surface; yet they flicker, as do our terrestrial flames, when we allow them time comparable to their gigantic dimensions. Drawings of the same prominence made at intervals of a few hours, or even less, often show great changes. The magnitude of the displacements that have been noticed sometimes attains many thousands of miles, and the actual velocity with which such masses move frequently exceeds 100 miles a second. Still more violent are the convulsions when, from the surface of the chromosphere, as from a mighty furnace, vast incandescent masses of gas are projected upwards. Plate IV. gives a view of a number of prominences as seen by Trouvelot at Harvard College Observatory, Cambridge, U.S.A. Trouvelot has succeeded in exhibiting in the different pictures the wondrous variety of aspect which these objects assume. The dimensions of the prominences may be inferred from the scale appended to the plate. The largest of those here shown is fully 80,000 miles high; and trustworthy observers have recorded prominences of an altitude even much greater. The rapid changes which these objects sometimes undergo are well illustrated in the two sketches on the left of the lowest line, which were drawn on April 27th, 1872. These are both drawings of the same prominence taken at an interval no greater than twenty minutes. This mighty flame is so vast that its length is ten times as great as the diameter of the earth, yet in this brief period it has completely changed its aspect; the upper part of the flame has, indeed, broken away, and is now shown in that part of the drawing between the two figures on the line above. The same plate also shows various instances of the remarkable spike-like objects, taken, however, at different times and at various parts of the sun. These spikes attain altitudes not generally greater than 20,000 miles, though sometimes they soar aloft to stupendous distances.

We may refer to one special object of this kind, the remarkable history of which has been chronicled by Professor Young. On October 7th, 1880, a prominence was seen, at about 10.30 a.m., on the south-east limb of the sun. It was then about 40,000 miles high, and attracted no special attention. Half an hour later a marvellous transformation had taken place. During that brief interval the prominence became very brilliant and doubled its length. For another hour the mighty flame still soared upwards, until it attained the unprecedented elevation of 350,000 miles—a distance more than one-third the diameter of the great luminary itself. At this climax the energy of the mighty outbreak seems to have at last become exhausted: the flame broke up into fragments,[Pg 58] and by 12.30—an interval of only two hours from the time when it was first noticed—the phenomenon had completely faded away.

No doubt this particular eruption was exceptional in its vehemence, and in the vastness of the changes of which it was an indication. The velocity of upheaval must have been at least 200,000 miles an hour, or, to put it in another form, more than fifty miles a second. This mighty flame leaped from the sun with a velocity more than 100 times as great as that of the swiftest bullet ever fired from a rifle.

The prominences may be generally divided into two classes. We have first those which are comparatively quiescent, and in form somewhat resemble the clouds which float in our earth's atmosphere. The second class of prominences are best described as eruptive. They are, in fact, thrown up from the chromosphere like gigantic jets of incandescent material. These two classes of objects differ not only in appearance but also in the gases of which they are composed. The cloud-like prominences consist mainly of hydrogen, with helium and calcium, while many metals are present in the eruptive discharges. The latter are never seen in the neighbourhood of the sun's poles, but generally appear close to a sun-spot, thus confirming the conclusion that the spots are associated with violent disturbances on the surface of the sun. When a spot has reached the limb of the sun it is frequently found to be surrounded by prominences. It has even been possible in a few instances to detect powerful gaseous eruptions in the neighbourhood of a spot, the spectroscope rendering them visible against the background of the solar surface just as the prominences are observed at the limb against the background of the sky.

In order to photograph a prominence we have, of course, to substitute a photographic plate for the observer's eye. Owing, however, to the difficulty of preventing the feeble light from the prominence from being overpowered by extraneous light, the photography of these bodies was not very successful until Professor Hale, of Chicago, designed his spectro-heliograph. In this instrument there is (in addition to the[Pg 59] usual slit through which the light falls on the prisms, or grating,) a second slit immediately in front of the photographic plate through which the light of a given wave-length can be permitted to pass to the exclusion of all the rest. The light chosen for producing an image of the prominences is that radiated in the remarkable "K line," due to calcium. This lies at the extreme end of the violet. The light from that part of the spectrum, though it is invisible to the eye, is much more active photographically than the light from the red, yellow, or green parts of the spectrum. The front slit is adjusted so that the K line falls upon the second slit, and as the front slit is slowly swept by clockwork over the whole of a prominence, the second slit keeps pace with it by a mechanical contrivance.

If the image of the solar disc is hidden by a screen of exactly the proper size, the slits may be made to sweep over the whole sun, thus giving us at one exposure a picture of the chromospheric ring round the sun's limb with its prominences. The screen may now be withdrawn, and the slits may be made to sweep rapidly over the disc itself. They reveal the existence of glowing calcium vapours in many parts of the surface of the sun. Thus we get a striking picture of the sun as drawn by this particular light. In this manner Professor Hale confirmed the observation made long before by Professor Young, that the spectra of faculæ always show the two great calcium bands.

The velocity with which a prominence shoots upward from the sun's limb can, of course, be measured directly by observations of the ordinary kind with a micrometer. The spectroscope, however, enables us to estimate the speed with which disturbances at the surface of the sun travel in the direction towards the earth or from the earth. We can measure this speed by watching the peculiar behaviour of the spectral lines representing the rapidly moving masses. This opens up a remarkable line of investigation with important applications in many branches of astronomy.

It is, of course, now generally understood that the sensation of light is caused by waves or undulations which impinge[Pg 60] on the retina of the eye after having been transmitted through that medium which we call the ether. To the different colours correspond different wave-lengths—that is to say, different distances between two successive waves. A beam of white light is formed by the union of innumerable different waves whose lengths have almost every possible value lying between certain limits. The wave-length of red light is such that there are 33,000 waves in an inch, while that of violet light is but little more than half that of red light. The position of a line in the spectrum depends solely on the wave-length of the light to which it is due. Suppose that the source of light is approaching directly towards the observer; obviously the waves follow each other more closely than if the source were at rest, and the number of undulations which his eye receives in a second must be proportionately increased. Thus the distance between two successive ether waves will be very slightly diminished. A well-known phenomenon of a similar character is the change of pitch of the whistle of a locomotive engine as it rushes past. This is particularly noticeable if the observer happens to be in a train which is moving rapidly in the opposite direction. In the case of sound, of course, the vibrations or waves take place in the air and not in the ether. But the effect of motion to or from the observer is strictly analogous in the two cases. As, however, light travels 186,000 miles a second, the source of light will also have to travel with a very high velocity in order to produce even the smallest perceptible change in the position of a spectral line.

We have already seen that enormously high velocities are by no means uncommon in some of these mighty disturbances on the sun; accordingly, when we examine the spectrum of a sun-spot, we often see that some of the lines are shifted a little towards one end of the spectrum and sometimes towards the other, while in other cases the lines are seen to be distorted or twisted in the most fantastic manner, indicating very violent local commotions. If the spot happens to be near the centre of the sun's disc, the gases must be shooting upwards or downwards to produce[Pg 61] these changes in the lines. The velocities indicated in observations of this class sometimes amount to as much as two or even three hundred miles per second. We find it difficult to conceive the enormous internal pressures which are required to impel such mighty masses of gases aloft from the photosphere with speeds so terrific, or the conditions which bring about the downrush of such gigantic masses of vapour from above. In the spectra of the prominences on the sun's limb also we often see the bright lines bent or shifted to one side. In such cases what we witness is evidently caused by movements along the surface of the chromosphere, conveying materials towards us or away from us.

An interesting application of this beautiful method of measuring the speed of moving bodies has been made in various attempts to determine the period of rotation of the sun spectroscopically. As the sun turns round on its axis, a point on the eastern limb is moving towards the observer and a point on the western limb is moving away from him. In each case the velocity is a little over a mile per second. At the eastern limb the lines in the solar spectrum are very slightly shifted towards the violet end of the spectrum, while the lines in the spectrum of the western limb are equally shifted towards the red end. By an ingenious optical contrivance it is possible to place the spectra from the two limbs side by side, which doubles the apparent displacement, and thus makes it much more easy to measure. Even with this contrivance the visual quantities to be measured remain exceedingly minute. All the parts of the instrument have to be most accurately adjusted, and the observations are correspondingly delicate. They have been attempted by various observers. Among the most successful investigations of this kind we may mention that of the Swedish astronomer, Dunér, who, by pointing his instrument to a number of places on the limb, found values in good agreement with the peculiar law of rotation which has been deduced from the motion of sun-spots. This result is specially interesting, as it shows that the atmospheric layers, in which that absorption takes[Pg 62] place which produces the dark lines in the spectrum, shares in the motion of the photosphere at the same latitude.

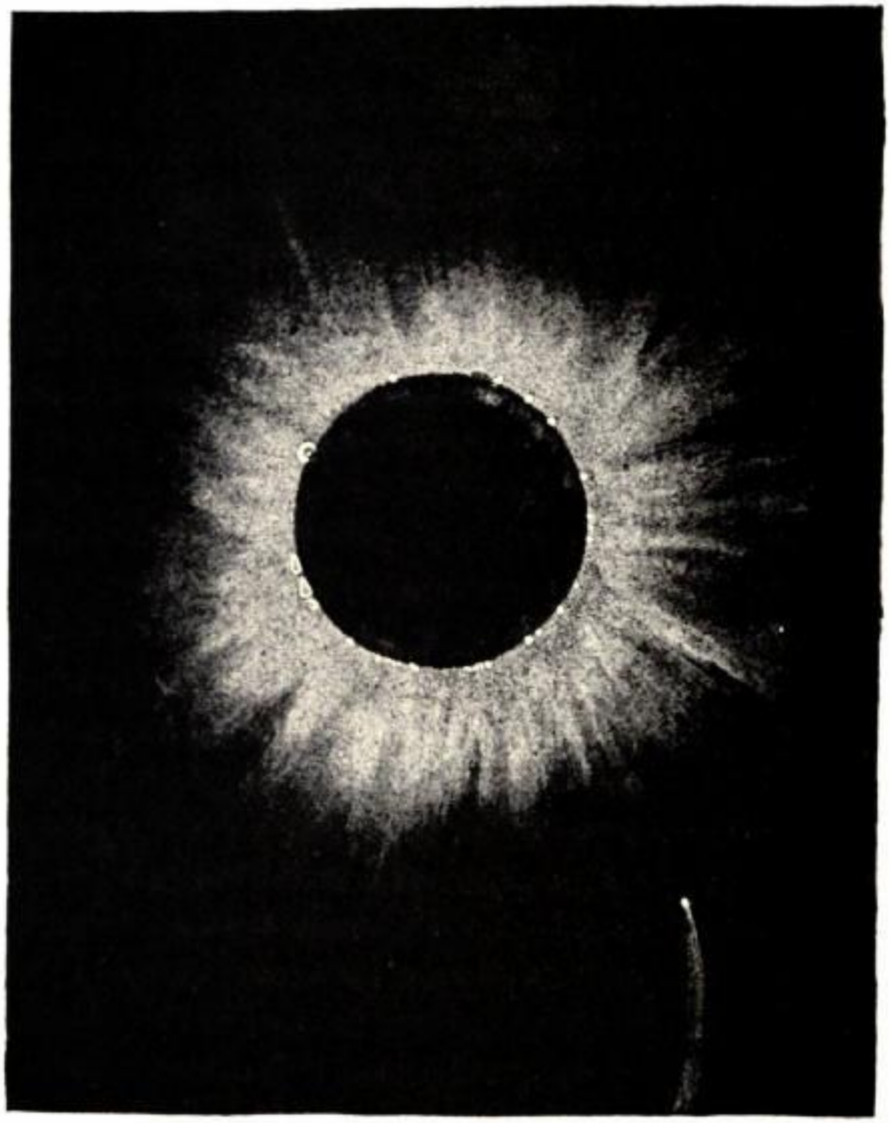

Fig. 20.—View of the Corona (and a Comet) in a Total Eclipse.

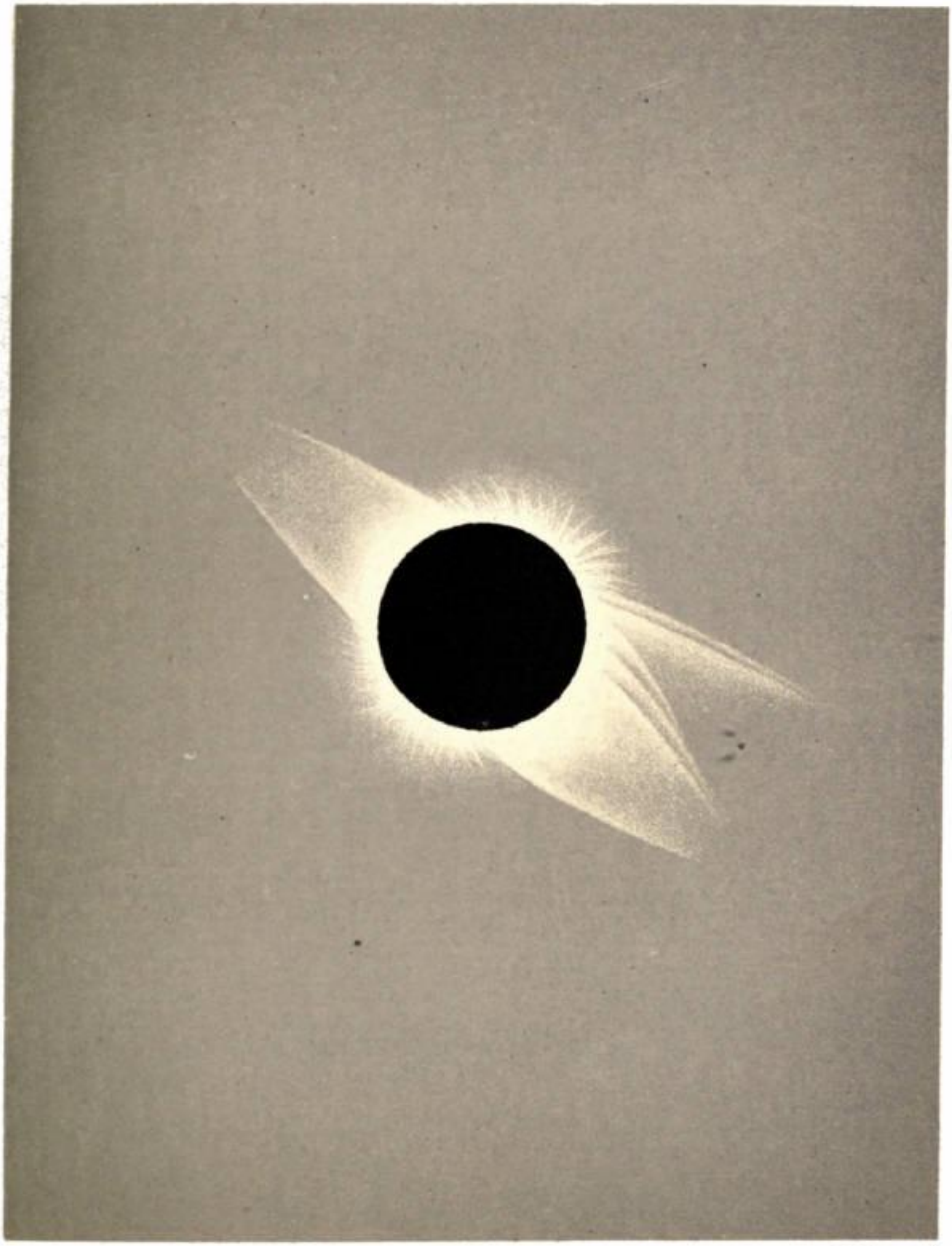

PLATE V.
TOTAL SOLAR ECLIPSE, JULY 29TH, 1878.
THE CORONA FROM THE PHOTOGRAPHS.
(HARKNESS.)

We have yet to mention one other striking phenomenon which is among the chief attractions to observers of total eclipses, and which it has hitherto not been found possible to see in full daylight. This is the corona or aureole of light which is suddenly seen to surround the sun in an eclipse when the moon has completely covered the last remaining crescent of the sun. A general idea of the appearance of the corona is given in Fig. 20, and we further present in Plate V. the drawing of the corona made by Professor Harkness from a comparison of a large number of photographs obtained at different places in the United States during the total eclipse of July 29th, 1878. In Fig. 21 we are permitted by the kindness of Mr. and Mrs. Maunder to reproduce the remarkable photograph of the corona which they obtained in India during the eclipse of January 22nd, 1898.

Fig. 21.—View of Corona during the Eclipse of Jan. 22nd, 1898
(*Reproduced by kind permission of Mr. and Mrs. Maunder and of the proprietors of "Knowledge."*)

The part of the corona nearest the sun is very bright, though not so brilliant as the prominences, which (as Professor Young says) blaze through it like[Pg 64] carbuncles. This inner portion is generally of fairly regular outline, forming a white ring about a tenth part of the solar diameter in width. The outer parts of the corona are usually very irregular and very extensive. They are often interrupted by narrow "rifts," or narrow dark bands, which reach from the limb of the sun through the entire corona. On the other hand, there are also sometimes narrow bright streamers, inclined at various angles to the limb of the sun and not seldom curved. In the eclipses of 1867, 1878, and 1889, all of which occurred at periods of sun-spot minimum, the corona showed long and faint streamers nearly in the direction of the sun's equator, and short but distinct brushes of light near the poles. In the eclipses of 1870, 1882, and 1893, near sun-spot maxima, the corona was more regularly circular, and chiefly developed over the spot zones. We have here another proof (if one were necessary) of the intimate connection between the periodicity of the spots and the development of all other solar phenomena.

In the spectrum of the corona there is a mysterious line in the green, as to the origin of which nothing is at present certainly known. It is best seen during eclipses occurring near the time of sun-spot maximum. It is presented in the ordinary solar spectrum as a very thin, dark line, which generally remains undisturbed even when lines of hydrogen and other substances are twisted and distorted by the violent rush of disturbed elements. The line is always present among the bright lines of the chromosphere spectrum. In addition to it the corona shows a few other bright lines, belonging, no doubt, to the same unknown element ("coronium"), and also a faint continuous spectrum, in which even a few of the more prominent dark lines of the solar spectrum have been sometimes detected. This shows that in addition to glowing gas (represented by the bright lines) the corona also contains a great deal of matter like dust, or fog, the minute particles of which are capable of reflecting the sunlight and thereby producing a feeble continuous spectrum. This matter seems to form the principal constituent of the long coronal rays and streamers, as the latter are not visible in the[Pg 65] detached images of the corona which appear instead of the bright lines when the corona is viewed, or photographed, during an eclipse, in a spectroscope without a slit. If the long rays were composed of the gas or gases which constitute the inner corona, it is evident that they ought to appear in these detached images. As to the nature of the forces which are continually engaged in shooting out these enormously long streamers, we have at present but little information. It is, however, certain that the extensive atmospheric envelope round the sun, which shows itself as the inner corona, must be extremely attenuated. Comets have on several occasions been known to rush through this coronal atmosphere without evincing the slightest appreciable diminution in their speed from the resistance to which they were exposed.

We have accumulated by observation a great number of facts concerning the sun, but when we try to draw from these facts conclusions as to the physical constitution of that great body, it cannot be denied that the difficulties seem to be very great indeed. We find that the best authorities differ considerably in the opinions they entertain as to its nature. We shall here set forth the principal conclusions as to which there is little or no controversy.

We shall see in a following chapter that astronomers have been able to determine the relative densities of the bodies in the solar system; in other words, they have found the relation between the quantities of matter contained in an equally large volume of each. It has thus been ascertained that the average density of the sun is about a quarter that of the earth. If we compare the weight of the sun with that of an equally great globe of water, we find that the luminary would be barely one and a half times as heavy as the water. Of course, the actual mass of the sun is very enormous; it is no less than 330,000 times as great as that of the earth. The solar material itself is, however, relatively light, so that the sun is four times as big as it would have to be if, while its weight remained the same, its density equalled that of the earth. Bearing in mind this lightness of the sun, and also the exceedingly high temperature which we know to prevail[Pg 66] there, no other conclusion seems possible than that the body of the sun must be in a gaseous state. The conditions under which such gases exist in the sun are, no doubt, altogether different from those with which we are acquainted on the earth. At the surface of the sun the force of gravity is more than twenty-seven times as great as it is on the earth. A person who on the earth could just lift twenty-seven equal pieces of metal would, if he were transferred to the sun, only be able to lift one of the pieces at a time. The pressure of the gases below the surface must therefore be very great, and it might be supposed that they would become liquefied in consequence. It was, however, discovered by Andrews that so long as a gas is kept at a temperature higher than a certain point, known as the "critical temperature" (which is different for different gases), the gas will not be turned into a liquid however great be the pressure to which it is submitted. The temperature on the sun cannot be lower than the critical temperatures of the gases there existing; so it would seem that even the enormous pressure can hardly reduce the gases in the great luminary to the liquid form.

Of the interior of the sun we can, of course, expect to learn little or nothing. What we observe is the surface-layer, the so-called photosphere, in which the cold of space produces the condensation of the gases into those luminous clouds which we see in our drawings and photographs as "rice grains" or "willow leaves." It has been suggested by Dr. Johnstone Stoney (and afterwards by Professor Hastings, of Baltimore) that these luminous clouds are mainly composed of carbon with those of the related elements silicon and boron, the boiling points of which are much higher than those of other elements which might be considered likely to form the photospheric clouds. The low atomic weight of carbon must also have the effect of giving the molecules of this element a very high velocity, and thereby enabling them to work their way into the upper regions, where the temperature has so fallen that the vapour becomes chilled into cloud. A necessary consequence of the rapid cooling of these clouds, and the consequent[Pg 67] radiation of heat on a large scale, would be the formation of what we may perhaps describe as smoke, which settles by degrees through the intervals between the clouds (making these intervals appear darker) until it is again volatilised on reaching a level of greater heat below the clouds. This same smoke is probably the cause of the well-known fact that the solar limb is considerably fainter than the middle of the disc. This seems to arise from the greater absorption caused by the longer distance which a ray of light from a point near the limb has to travel through this layer of smoke before reaching the earth. It is shown that this absorption cannot be attributed to a gaseous atmosphere, since this would have the effect of producing more dark absorption lines in the spectrum. There would thus be a marked difference between the solar spectrum from a part near the middle of the disc and the spectrum from a part near the limb. This, however, we do not find to be the case.

With regard to the nature of sun-spots, the idea first suggested by Secchi and Lockyer, that they represent down rushes of cooler vapours into the photosphere (or to its surface), seems on the whole to accord best with the observed phenomena. We have already mentioned that the spots are generally accompanied by faculæ and eruptive prominences in their immediate neighbourhood, but whether these eruptions are caused by the downfall of the vapour which makes the photospheric matter "splash up" in the vicinity, or whether the eruptions come first, and by diminishing the upward pressure from below form a "sink," into which overlying cooler vapour descends, are problems as to which opinions are still much divided.

A remarkable appendage to the sun, which extends to a distance very much greater than that of the corona, produces the phenomenon of the zodiacal light. A pearly glow is sometimes seen in the spring to spread over a part of the sky in the vicinity of the point where the sun has disappeared after sunset. The same spectacle may also be witnessed before sunrise in the autumn, and it would seem as if the material producing the zodiacal light, whatever it may be, had a[Pg 68] lens-shaped form with the sun in the centre. The nature of this object is still a matter of uncertainty, but it is probably composed of a kind of dust, as the faint spectrum it affords is of a continuous type. A view of the zodiacal light is shown in Fig. 22.

In all directions the sun pours forth, with the most prodigal liberality, its torrents of light and of heat. The earth can only grasp the merest fraction, less than the 2,000,000,000th part of the whole. Our fellow planets and the moon also intercept a trifle; but how small is the portion of the mighty flood which they can utilise! The sip that a flying swallow takes from a river is as far from exhausting the water in the river as are the planets from using all the heat which streams from the sun.

The sun's gracious beams supply the magic power that enables the corn to grow and ripen. It is the heat of the sun which raises water from the ocean in the form of vapour, and then sends down that vapour as rain to refresh the earth and to fill the rivers which bear our ships down to the ocean. It is the heat of the sun beating on the large continents which gives rise to the breezes and winds that waft our vessels across the deep; and when on a winter's evening we draw around the fire and feel its invigorating rays, we are only enjoying sunbeams which shone on the earth countless ages ago. The heat in those ancient sunbeams developed the mighty vegetation of the coal period, and in the form of coal that heat has slumbered for millions of years, till we now call it again into activity. It is the power of the sun stored up in coal that urges on our steam-engines. It is the light of the sun stored up in coal that beams from every gaslight in our cities.

For the power to live and move, for the plenty with which we are surrounded, for the beauty with which nature is adorned, we are immediately indebted to one body in the countless hosts of space, and that body is the sun.

[Pg 69]

Fig. 22.—The Zodiacal Light in 1874.

[Pg 70]

CHAPTER III.

THE MOON.

The Moon and the Tides—The Use of the Moon in Navigation—The Changes of the Moon—The Moon and the Poets—Whence the Light of the Moon?—Sizes of the Earth and the Moon—Weight of the Moon—Changes in Apparent Size—Variations in its Distance—Influence of the Earth on the Moon—The Path of the Moon—Explanation of the Moon's Phases—Lunar Eclipses—Eclipses of the Sun, how produced—Visibility of the Moon in a Total Eclipse—How Eclipses are Predicted—Uses of the Moon in finding Longitude—The Moon not connected with the Weather—Topography of the Moon—Nasmyth's Drawing of Triesnecker—Volcanoes on the Moon—Normal Lunar Crater—Plato—The Shadows of Lunar Mountains—The Micrometer—Lunar Heights—Former Activity on the Moon—Nasmyth's View of the Formation of Craters—Gravitation on the Moon—Varied Sizes of the Lunar Craters—Other Features of the Moon—Is there Life on the Moon?—Absence of Water and of Air—Dr. Stoney's Theory—Explanation of the Rugged Character of Lunar Scenery—Possibility of Life on Distant Bodies in Space.

If the moon were suddenly struck out of existence, we should be immediately apprised of the fact by a wail from every seaport in the kingdom. From London and from Liverpool we should hear the same story—the rise and fall of the tide had almost ceased. The ships in dock could not get out; the ships outside could not get in; and the maritime commerce of the world would be thrown into dire confusion.

The moon is the principal agent in causing the daily ebb and flow of the tide, and this is the most important work which our satellite has to do. The fleets of fishing boats around the coasts time their daily movements by the tide, and are largely indebted to the moon for bringing them in and out of harbour. Experienced sailors assure us that the tides are of the utmost service to navigation. The question as to how the moon causes the tides is postponed to a future chapter, in which we shall also sketch the marvellous part which[Pg 71] the tides seem to have played in the early history of our earth.

Who is there that has not watched, with admiration, the beautiful series of changes through which the moon passes every month? We first see her as an exquisite crescent of pale light in the western sky after sunset. If the night is fine, the rest of the moon is visible inside the crescent, being faintly illumined by light reflected from our own earth. Night after night she moves further and further to the east, until she becomes full, and rises about the same time that the sun sets. From the time of the full the disc of light begins to diminish until the last quarter is reached. Then it is that the moon is seen high in the heavens in the morning. As the days pass by, the crescent shape is again assumed. The crescent wanes thinner and thinner as the satellite draws closer to the sun. Finally she becomes lost in the overpowering light of the sun, again to emerge as the new moon, and again to go through the same cycle of changes.

The brilliance of the moon arises solely from the light of the sun, which falls on the not self-luminous substance of the moon. Out of the vast flood of light which the sun pours forth with such prodigality into space the dark body of the moon intercepts a little, and of that little it reflects a small fraction to illuminate the earth. The moon sheds so much light, and seems so bright, that it is often difficult at night to remember that the moon has no light except what falls on it from the sun. Nevertheless, the actual surface of the brightest full moon is perhaps not much brighter than the streets of London on a clear sunshiny day. A very simple observation will suffice to show that the moon's light is only sunlight. Look some morning at the moon in daylight, and compare the moon with the clouds. The brightness of the moon and of the clouds are directly comparable, and then it can be readily comprehended how the sun which illuminates the clouds has also illumined the moon. An attempt has been made to form a comparative estimate of the brightness of the sun and the full moon. If 600,000 full moons were shining at once, their collective brilliancy would equal that of the sun.[Pg 72]

The beautiful crescent moon has furnished a theme for many a poet. Indeed, if we may venture to say so, it would seem that some poets have forgotten that the moon is not to be seen every night. A poetical description of evening is almost certain to be associated with the appearance of the moon in some phase or other. We may cite one notable instance in which a poet, describing an historical event, has enshrined in exquisite verse a statement which cannot be correct. Every child who speaks our language has been taught that the burial of Sir John Moore took place

"By the struggling moonbeams' misty light."

There is an appearance of detail in this statement which wears the garb of truth. We are not inclined to doubt that the night was misty, nor as to whether the moonbeams had to struggle into visibility; the question at issue is a much more fundamental one. We do not know who was the first to raise the point as to whether any moon shone on that memorable event at all or not; but the question having been raised, the Nautical Almanac immediately supplies an answer. From it we learn in language, whose truthfulness constitutes its only claim to be poetry, that the moon was new at one o'clock in the morning of the day of the battle of Corunna (16th January, 1809). The ballad evidently implies that the funeral took place on the night following the battle. We are therefore assured that the moon can hardly have been a day old when the hero was consigned to his grave. But the moon in such a case is practically invisible, and yields no appreciable moonbeams at all, misty or otherwise. Indeed, if the funeral took place at the "dead of night," as the poet asserts, then the moon must have been far below the horizon at the time.[6]

In alluding to this and similar instances, Mr. Nasmyth gives a word of advice to authors or to artists who desire to bring the moon on a scene without knowing as a matter of fact[Pg 73] that our satellite was actually present. He recommends them to follow the example of Bottom in *A Midsummer's Night's Dream*, and consult "a calendar, a calendar! Look in the almanac; find out moonshine, find out moonshine!"

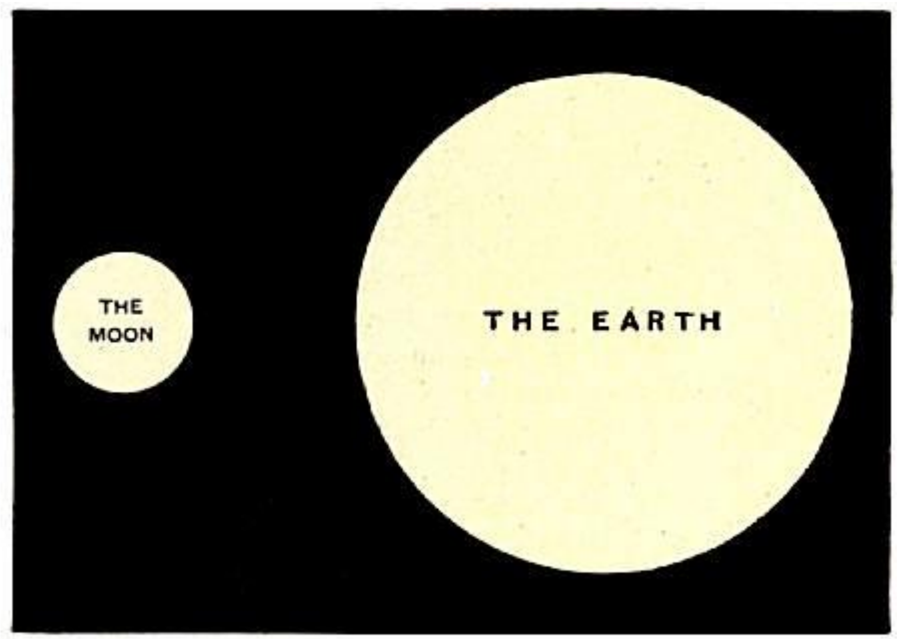

Fig. 23.—Comparative Sizes of the Earth and the Moon.

Among the countless host of celestial bodies—the sun, the moon, the planets, and the stars—our satellite enjoys one special claim on our attention. The moon is our nearest permanent neighbour. It is just possible that a comet may occasionally approach the earth more closely than the moon but with this exception the other celestial bodies are all many hundreds or thousands, or even many millions, of times further from us than the moon.

It is also to be observed that the moon is one of the smallest visible objects which the heavens contain. Every one of the thousands of stars that can be seen with the unaided eye is enormously larger than our satellite. The brilliance and apparent vast proportions of the moon arise from the fact that it is only 240,000 miles away, which is a distance almost[Pg 74] immeasurably small when compared with the distances between the earth and the stars.

Fig. 23 exhibits the relative sizes of the earth and its attendant. The small globe shows the moon, while the larger globe represents the earth. When we measure the actual diameters of the two globes, we find that of the earth to be 7,918 miles and of the moon 2,160 miles, so that the diameter of the earth is nearly four times greater than the diameter of the moon. If the earth were cut into fifty pieces, all equally large, then one of these pieces rolled into a globe would equal the size of the moon. The superficial extent of the moon is equal to about one thirteenth part of the surface of the earth. The hemisphere our neighbour turns towards us exhibits an area equal to about one twenty-seventh part of the area of the earth. This, to speak approximately, is about double the actual extent of the continent of Europe. The average materials of the earth are, however, much heavier than those contained in the moon. It would take more than eighty globes, each as ponderous as the moon, to weigh down the earth.

Amid the changes which the moon presents to us, one obvious fact stands prominently forth. Whether our satellite be new or full, at first quarter or at last, whether it be high in the heavens or low near the horizon, whether it be in process of eclipse by the sun, or whether the sun himself is being eclipsed by the moon, the apparent size of the latter is nearly constant. We can express the matter numerically. A globe one foot in diameter, at a distance of 111 feet from the observer, would under ordinary circumstances be just sufficient to hide the disc of the moon; occasionally, however, the globe would have to be brought in to a distance of only 103 feet, or occasionally it might have to be moved out to so much as 118 feet, if the moon is to be exactly hidden. It is unusual for the moon to approach either of its extreme limits of position, so that the distance from the eye at which the globe must be situated so as to exactly cover the moon is usually more than 105 feet, and less than 117 feet. These fluctuations in the apparent size of our satellite are contained within such narrow limits that in the first glance at the[Pg 75] subject they may be overlooked. It will be easily seen that the apparent size of the moon must be connected with its real distance from the earth. Suppose, for the sake of illustration, that the moon were to recede into space, its size would seem to dwindle, and long ere it had reached the distance of even the very nearest of the other celestial bodies it would have shrunk into insignificance. On the other hand, if the moon were to come nearer to the earth, its apparent size would gradually increase until, when close to our globe, it would seem like a mighty continent stretching over the sky. We find that the apparent size of the moon is nearly constant, and hence we infer that the average distance of the same body is also nearly constant. The average value of that distance is 239,000 miles. In rare circumstances it may approach to a distance but little more than 221,000 miles, or recede to a distance hardly less than 253,000 miles, but the ordinary fluctuations do not exceed more than about 13,000 miles on either side of its mean value.

From the moon's incessant changes we perceive that she is in constant motion, and we now further see that whatever these movements may be, the earth and the moon must at present remain at *nearly* the same distance apart. If we further add that the path pursued by the moon around the heavens lies nearly in a plane, then we are forced to the conclusion that our satellite must be revolving in a nearly circular path around the earth at the centre. It can, indeed, be shown that the constant distance of the two bodies involves as a necessary condition the revolution of the moon around the earth. The attraction between the moon and the earth tends to bring the two bodies together. The only way by which such a catastrophe can be permanently avoided is by making the satellite move as we actually find it to do. The attraction between the earth and the moon still exists, but its effect is not then shown in bringing the moon in towards the earth. The attraction has now to exert its whole power in restraining the moon in its circular path; were the attraction to cease, the moon would start off in a straight line, and recede never to return.

[Pg 76]

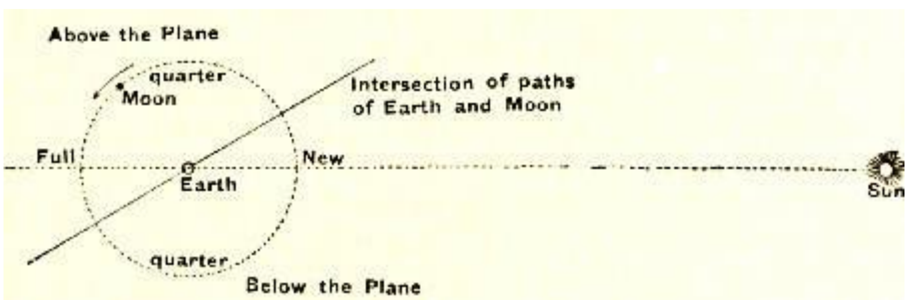

Fig. 24.—The Moon's Path around the Sun.

The fact of the moon's revolution around the earth is easily demonstrated by observations of the stars. The rising and setting of our satellite is, of course, due to the rotation of the earth, and this apparent diurnal movement the moon possesses in common with the sun and with the stars. It will, however, be noticed that the moon is continually changing its place among the stars. Even in the course of a single night the displacement will be conspicuous to a careful observer without the aid of a telescope. The moon completes each revolution around the earth in a period of 27·3 days.

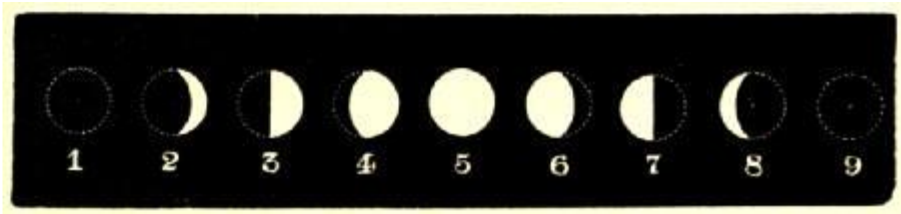

Fig. 25.—The Phases of the Moon.

In Fig. 24 we have a view of the relative positions of the earth, the sun, and the moon, but it is to be observed that, for the convenience of illustration, we have been obliged to represent the orbit of the moon on a much larger scale than it ought to be in comparison with the distance of the sun. That half of the moon which is turned towards the sun is brilliantly illuminated, and, according as we see more or less of that brilliant half, we say that the moon is more or less full, the several "phases" being visible in the succession shown by the numbers in Fig. 25. A beginner sometimes finds [Pg 77]considerable difficulty in understanding how the light on the full moon at night can have been derived from the sun. "Is not," he will say, "the earth in the way? and must it not intercept the sunlight from every object on the other side of the earth to the sun?" A study of Fig. 24 will explain the difficulty. The plane in which the moon revolves does not coincide with the plane in which the earth revolves around the sun. The line in which the plane of the earth's motion is intersected by that of the moon divides the moon's path into two semicircles. We must imagine the moon's path to be tilted a little, so that the upper semicircle is somewhat above the plane of the paper, and the other semicircle below. It thus follows that when the moon is in the position marked full, under the circumstances shown in the figure, the moon will be just above the line joining the earth and the sun; the sunlight will thus pass over the earth to the moon, and the moon will be illuminated. At new moon, the moon will be under the line joining the earth and the sun.

As the relative positions of the earth and the sun are changing, it happens twice in each revolution that the sun comes into the position of the line of intersection of the two planes. If this occurs at the time of full moon, the earth lies directly between the moon and the sun; the moon is thus plunged into the shadow of the earth, the light from the sun is intercepted, and we say that the moon is eclipsed. The moon sometimes only partially enters the earth's shadow, in which case the eclipse is a partial one. When, on the other hand, the sun is situated on the line of intersection at the time of new moon, the moon lies directly between the earth and the sun, and the dark body of the moon will then cut off the sunlight from the earth, producing a solar eclipse. Usually only a part of the sun is thus obscured, forming the well-known partial eclipse; if, however, the moon pass centrally over the sun, then we must have one or other of two very remarkable kinds of eclipse. Sometimes the moon entirely blots out the sun, and thus is produced the sublime spectacle of a total eclipse, which tells us so much as to the nature of the sun, and to which we have already referred in the last[Pg 78] chapter. Even when the moon is placed centrally over the sun, a thin rim of sunlight is occasionally seen round the margin of the moon. We then have what is known as an annular eclipse.

It is remarkable that the moon is sometimes able to hide the sun completely, while on other occasions it fails to do so. It happens that the average apparent size of the moon is nearly equal to the average apparent size of the sun, but, owing to the fluctuations in their distances, the actual apparent sizes of both bodies undergo certain changes. On certain occasions the apparent size of the moon is greater than that of the sun. In this case a central passage produces a total eclipse; but it may also happen that the apparent size of the sun exceeds that of the moon, in which case a central passage can only produce an annular eclipse.

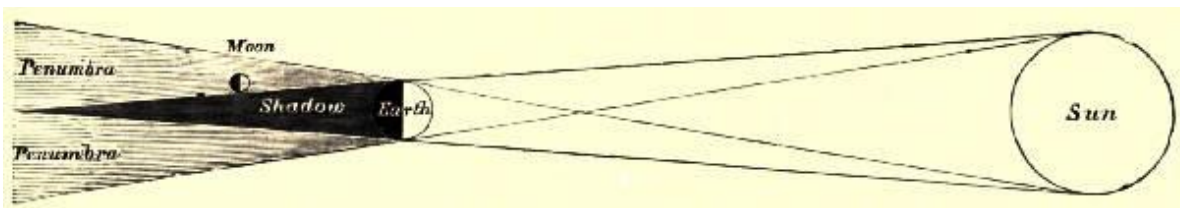

Fig. 26.—Form of the Earth's Shadow, showing the Penumbra, or partially shaded region. Within the Penumbra, the Moon is visible; in the Shadow it is nearly invisible.

There are hardly any more interesting celestial phenomena than the different descriptions of eclipses. The almanac will always give timely notice of the occurrence, and the more striking features can be observed without a telescope. In an eclipse of the moon (Fig. 26) it is interesting to note the moment when the black shadow is first detected, to watch its gradual encroachment over the bright surface of the moon, to follow it, in case the eclipse is total, until there is only a thin crescent of moonlight left, and to watch the final extinction of that crescent when the whole moon is plunged into the shadow. But now a spectacle of great interest and beauty is often manifested; for though the moon is so hidden behind the[Pg 79] earth that not a single direct ray of the sunlight could reach its surface, yet we often find that the moon remains visible, and, indeed, actually glows with a copper-coloured hue bright enough to permit several of the markings on the surface to be discerned.

This illumination of the moon even in the depth of a total eclipse is due to the sunbeams which have just grazed the edge of the earth. In doing so they have become bent by the refraction of the atmosphere, and have thus been turned inwards into the shadow. Such beams have passed through a prodigious thickness of the earth's atmosphere, and in this long journey through hundreds of miles of air they have become tinged with a ruddy or copper-like hue. Nor is this property of our atmosphere an unfamiliar one. The sun both at sunrise and at sunset glows with a light which is much more ruddy than the beams it dispenses at noonday. But at sunset or at sunrise the rays which reach our eyes have much more of our atmosphere to penetrate than they have at noon, and accordingly the atmosphere imparts to them that ruddy colour so characteristic and often so lovely. If the spectrum of the sun when close to the horizon is examined it is seen to be filled with numerous dark lines and bands situated chiefly towards the blue and violet end. These are caused by the increased absorption which the light suffers in the atmosphere, and give rise to the preponderating red light on the sun under such conditions. In the case of the eclipsed moon, the sunbeams have to take an atmospheric journey more than double as long as that at sunrise or sunset, and hence the ruddy glow of the eclipsed moon may be accounted for.

The almanacs give the full particulars of each eclipse that happens in the corresponding year. These predictions are reliable, because astronomers have been carefully observing the moon for ages, and have learned from these observations not only how the moon moves at present, but also how it will move for ages to come. The actual calculations are so complicated that we cannot here discuss them. There is, however, one leading principle about eclipses which is so simple that we must refer to it. The eclipses occurring this year have no[Pg 80] very obvious relation to the eclipses that occurred last year, or to those that will occur next year. Yet, when we take a more extended view of the sequence of these phenomena, a very definite principle becomes manifest. If we observe all the eclipses in a period of eighteen years, or nineteen years, then we can predict, with at least an approximation to the truth, all the future eclipses for many years. It is only necessary to recollect that in 6,585-1⁄3 days after one eclipse a nearly similar eclipse follows. For instance, a beautiful eclipse of the moon occurred on the 5th of December, 1881. If we count back 6,585 days from that date, or, that is, eighteen years and eleven days, we come to November 24th, 1863, and a similar eclipse of the moon took place then. Again, there were four eclipses in the year 1881. If we add 6,585-1⁄3 days to the date of each eclipse, it will give the dates of all the four eclipses in the year 1899. It was this rule which enabled the ancient astronomers to predict the recurrence of eclipses, at a time when the motions of the moon were not understood nearly so well as they now are.

During a long voyage, and perhaps in critical circumstances, the moon will often render invaluable information to the sailor. To navigate a ship, suppose from Liverpool to China, the captain must frequently determine the precise position which his ship then occupies. If he could not do this, he would never find his way across the trackless ocean. Observations of the sun give him his latitude and tell him his local time, but the captain further requires to know the Greenwich time before he can place his finger at a point of the chart and say, "My ship is here." To ascertain the Greenwich time the ship carries a chronometer which has been carefully rated before starting, and, as a precaution, two or three chronometers are usually provided to guard against the risk of error. An unknown error of a minute in the chronometer might perhaps lead the vessel fifteen miles from its proper course.

PLATE VI.
CHART OF THE MOON'S SURFACE.

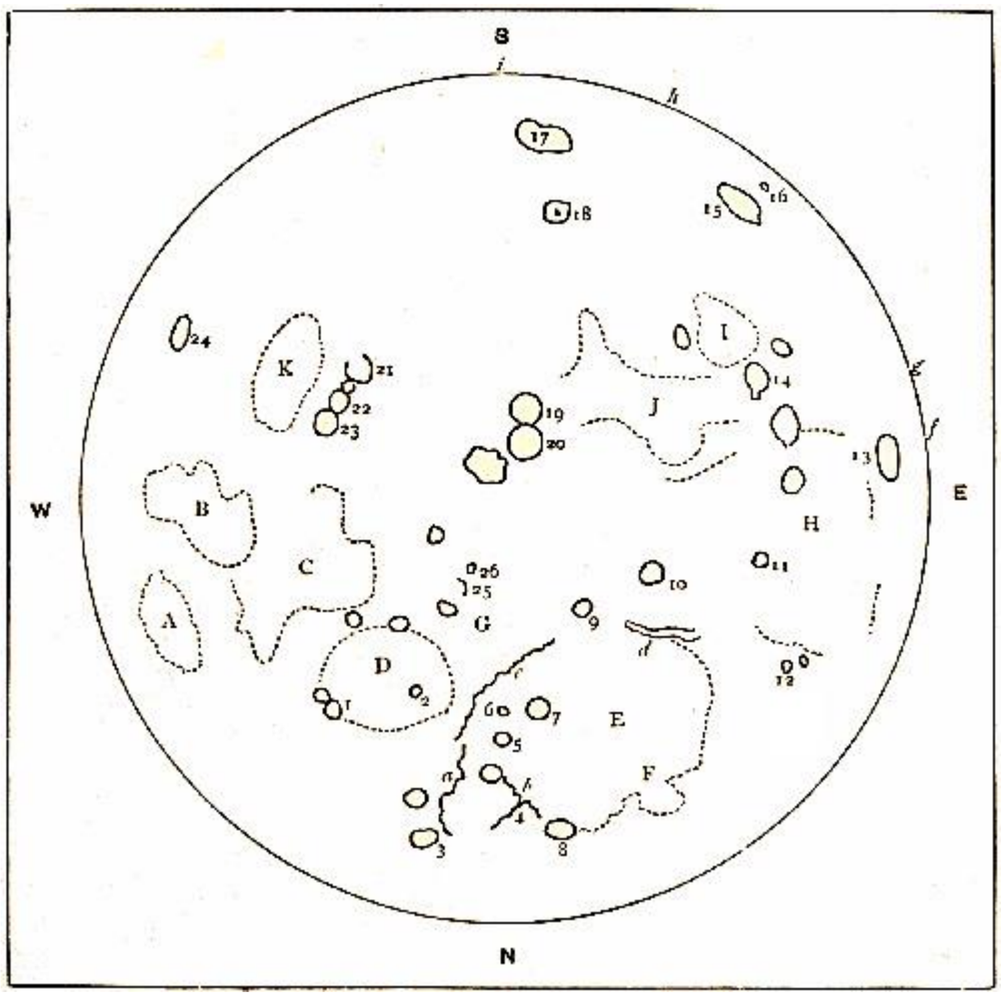

Fig. 27.—Key to Chart of the Moon (Plate VI.).

It is important to have the means of testing the chronometers during the progress of the voyage; and it would be a great convenience if every captain, when he wished, could actually consult some infallible standard of Greenwich time. We want, in fact, a Greenwich clock which may be visible over the whole globe. There is such a clock; and, like any other clock, it has a face on which certain marks are made, and a hand which travels round that face. The great clock at Westminster shrinks into insignificance when compared with the mighty clock which the captain uses for setting his chronometer. The face of this stupendous dial is the face of the heavens. The numbers engraved on the face of a clock are replaced by the twinkling stars; while the hand which moves over the dial is the beautiful moon herself.[Pg 82] When the captain desires to test his chronometer, he measures the distance of the moon from a neighbouring star. For example, he may see that the moon is three degrees from the star Regulus. In the Nautical Almanac he finds the Greenwich time at which the moon was three degrees from Regulus. Comparing this with the indications of the chronometer, he finds the required correction.

There is one widely-credited myth about the moon which must be regarded as devoid of foundation. The idea that our satellite and the weather bear some relation has no doubt been entertained by high authority, and appears to be an article in the belief of many an excellent mariner. Careful comparison between the state of the weather and the phases of the moon has, however, quite discredited the notion that any connection of the kind does really exist.

We often notice large blank spaces on maps of Africa and of Australia which indicate our ignorance of parts of the interior of those great continents. We can find no such blank spaces in the map of the moon. Astronomers know the surface of the moon better than geographers know the interior of Africa. Every spot on the face of the moon which is as large as an English parish has been mapped, and all the more important objects have been named.

A general map of the moon is shown in Plate VI. It has been based upon drawings made with small telescopes, and it gives an entire view of that side of our satellite which is presented towards us. The moon is shown as it appears in an astronomical telescope, which inverts everything, so that the south is at the top and the north at the bottom (to show objects upright a telescope requires an additional pair of lenses in the eye-piece, and as this diminishes the amount of light reaching the eye they are dispensed with in astronomical telescopes). We can see on the map some of the characteristic features of lunar scenery. Those dark regions so conspicuous in the ordinary full moon are easily recognised on the map. They were thought to be seas by astronomers before the days of telescopes, and indeed the name "Mare" is still retained, though it is obvious that they contain no[Pg 83] water at present. The map also shows certain ridges or elevated portions, and when we apply measurement to these objects we learn that they must be mighty mountain ranges. But the most striking features on the moon are those ring-like objects which are scattered over the surface in profusion. These are known as the lunar craters.

To facilitate reference to the chief points of interest we have arranged an index map (Fig. 27) which will give a clue to the names of the several objects depicted upon the plate. The so-called seas are represented by capital letters; so that A is the Mare Crisium, and H the Oceanus Procellarum. The ranges of mountains are indicated by small letters; thus a on the index is the site of the so-called Caucasus mountains, and similarly the Apennines are denoted by *c*. The numerous craters are distinguished by numbers; for example, the feature on the map corresponding to 20 on the index is the crater designated Ptolemy.

A. Mare Crisium.
B. Mare Fœcunditatis.
C. Mare Tranquillitatis.
D. Mare Serenitatis.
E. Mare Imbrium.
F. Sinus Iridum.
G. Mare Vaporum.
H. Oceanus Procellarum.
I. Mare Humorum.
J. Mare Nubium.
K. Mare Nectaris.

a. Caucasus.
b. Alps.
c. Apennines.
d. Carpathians.
f. Cordilleras & D'Alembert mountains.
g. Rook mountains.
h. Dœrfel mountains.
i. Leibnitz mountains.

1. Posidonius.
2. Linné.
3. Aristotle.
4. Great Valley of the Alps.
5. Aristillus.
6. Autolycus.
7. Archimedes.
8. Plato.
9. Eratosthenes.
10. Copernicus.
11. Kepler.
12. Aristarchus.
13. Grimaldi.
14. Gassendi.

15. Schickard.
16. Wargentin.
17. Clavius.
18. Tycho.
19. Alphonsus.
20. Ptolemy.
21. Catharina.
22. Cyrillus.
23. Theophilus.
24. Petavius.
25. Hyginus.
26. Triesnecker.

In every geographical atlas there is a map showing the two hemispheres of the earth, the eastern and the western. In the case of the moon we can only give a map of one hemisphere, for the simple reason that the moon always turns the same side towards us, and accordingly we never get a view of the other side. This is caused by the interesting circumstance that the moon takes exactly the same time to turn[Pg 84] once round its own axis as it takes to go once round the earth. The rotation is, however, performed with uniform speed, while the moon does not move in its orbit with a perfectly uniform velocity (*see* Chapter IV.). The consequence is that we now get a slight glimpse round the east limb, and now a similar glimpse round the west limb, as if the moon were shaking its head very gently at us. But it is only an insignificant margin of the far side of the moon which this *libration* permits us to examine.

Lunar objects are well suited for observation when the sunlight falls upon them in such a manner as to exhibit strongly contrasted lights and shadows. It is impossible to observe the moon satisfactorily when it is full, for then no conspicuous shadows are cast. The most opportune moment for seeing any particular lunar object is when it lies just at the illuminated side of the boundary between light and shade, for then the features are brought out with exquisite distinctness.

Plate VII.[7] gives an illustration of lunar scenery, the object represented being known to astronomers by the name of Triesnecker. The district included is only a very small fraction of the entire surface of the moon, yet the actual area is very considerable, embracing as it does many hundreds of square miles. We see in it various ranges of lunar mountains, while the central object in the picture is one of those remarkable lunar craters which we meet with so frequently in every lunar landscape. This crater is about twenty miles in diameter, and it has a lofty mountain in the centre, the peak of which is just illuminated by the rising sun in that phase of our satellite which is represented in the picture.

[Pg 85]

A typical view of a lunar crater is shown in Plate VIII. This is, no doubt, a somewhat imaginary sketch. The point of view from which the artist is supposed to have taken the picture is one quite unattainable by terrestrial astronomers, yet there can be little doubt that it is a fair representation of objects on the moon. We should, however, recollect the scale on which it is drawn. The vast crater must be many miles across, and the mountain at its centre must be thousands of feet high. The telescope will, even at its best, only show the moon as well as we could see it with the unaided eye if it were 250 miles away instead of being 240,000. We must not, therefore, expect to see any details on the moon even with the finest telescopes, unless they were coarse enough to be visible at a distance of 250 miles. England from such a point of view would only show London as a coloured spot, in contrast with the general surface of the country.

We return, however, from a somewhat fancy sketch to a more prosaic examination of what the telescope does actually reveal. Plate IX. represents the large crater Plato, so well known to everyone who uses a telescope. The floor of this remarkable object is nearly flat, and the central mountain, so often seen in other craters, is entirely wanting. We describe it more fully in the general list of lunar objects.

The mountain peaks on the moon throw long, well-defined shadows, characterised by a sharpness which we do not find in the shadows of terrestrial objects. The difference between the two cases arises from the absence of air from the moon. Our atmosphere diffuses a certain amount of light, which mitigates the blackness of terrestrial shadows and tends to soften their outline. No such influences are at work on the moon, and the sharpness of the shadows is taken advantage of in our attempts to measure the heights of the lunar mountains.

It is often easy to compute the altitude of a church steeple, a lofty chimney, or any similar object, from the length of its shadow. The simplest and the most accurate process is to measure at noon the number of feet from the base of the object[Pg 86] to the end of the shadow. The elevation of the sun at noon on the day in question can be obtained from the almanac, and then the height of the object follows by a simple calculation. Indeed, if the observations can be made either on the 6th of April or the 6th of September, at or near the latitude of London, then calculations would be unnecessary. The noonday length of the shadow on either of the dates named is equal to the altitude of the object. In summer the length of the noontide shadow is less than the altitude; in winter the length of the shadow exceeds the altitude. At sunrise or sunset the shadows are, of course, much longer than at noon, and it is shadows of this kind that we observe on the moon. The necessary measurements are made by that indispensable adjunct to the equatorial telescope known as the *micrometer*.

This word denotes an instrument for measuring *small* distances. In one sense the term is not a happy one. The objects to which the astronomer applies the micrometer are usually anything but small. They are generally of the most transcendent dimensions, far exceeding the moon or the sun, or even our whole system. Still, the name is not altogether inappropriate, for, vast though the objects may be, they generally seem minute, even in the telescope, on account of their great distance.

We require for such measurements an instrument capable of the greatest nicety. Here, again, we invoke the aid of the spider, to whose assistance in another department we have already referred. In the filar micrometer two spider lines are parallel, and one intersects them at right angles. One or both of the parallel lines can be moved by means of screws, the threads of which have been shaped by consummate workmanship. The distance through which the line has been moved is accurately indicated by noting the number of revolutions and parts of a revolution of the screw. Suppose the two lines be first brought into coincidence, and then separated until the apparent length of the shadow of the mountain on the moon is equal to the distance between the lines: we then know the number of revolutions of the micrometer screw which is equivalent to the length of the shadow. The number of miles on[Pg 87] the moon which correspond to one revolution of the screw has been previously ascertained by other observations, and hence the length of the shadow can be determined. The elevation of the sun, as it would have appeared to an observer at this point of the moon, at the moment when the measures were being made, is also obtainable, and hence the actual elevation of the mountain can be calculated. By measurements of this kind the altitudes of other lunar objects, such, for example, as the height of the rampart surrounding a circular-walled plane, can be determined.

The beauty and interest of the moon as a telescopic object induces us to give to the student a somewhat detailed account of the more remarkable features which it presents. Most of the objects we are to describe can be effectively exhibited with very moderate telescopic power. It is, however, to be remembered that all of them cannot be well seen at one time. The region most distinctly shown is the boundary between light and darkness. The student will, therefore, select for observation such objects as may happen to lie near that boundary at the time when he is observing.

1. *Posidonius.*—The diameter of this large crater is nearly 60 miles. Although its surrounding wall is comparatively slender, it is so distinctly marked as to make the object very conspicuous. As so frequently happens in lunar volcanoes, the bottom of the crater is below the level of the surrounding plain, in the present instance to the extent of nearly 2,500 feet.

2. *Linné.*—This small crater lies in the Mare Serenitatis. About sixty years ago it was described as being about 6-1⁄2 miles in diameter, and seems to have been sufficiently conspicuous. In 1866 Schmidt, of Athens, announced that the crater had disappeared. Since then an exceedingly small shallow depression has been visible, but the whole object is now very inconsiderable. This seems to be the most clearly attested case of change in a lunar object. Apparently the walls of the crater have tumbled into the interior and partly filled it up, but many astronomers doubt that a change has really taken place, as Schröter, a Hanoverian observer at the end of the eighteenth century, appears not to have seen any[Pg 88] conspicuous crater in the place, though it must be admitted that his observations are rather incomplete. To give some idea of Schmidt's amazing industry in lunar researches, it may be mentioned that in six years he made nearly 57,000 individual settings of his micrometer in the measurement of lunar altitudes. His great chart of the mountains in the moon is based on no less than 2,731 drawings and sketches, if those are counted twice that may have been used for two divisions of the map.

3. *Aristotle.*—This great philosopher's name has been attached to a grand crater 50 miles in diameter, the interior of which, although very hilly, shows no decidedly marked central cone. But the lofty wall of the crater, exceeding 10,500 feet in height, overshadows the floor so continuously that its features are never seen to advantage.

4. *The Great Valley of the Alps.*—A wonderfully straight valley, with a width ranging from 3-1⁄2 to 6 miles, runs right through the lunar Alps. It is, according to Mädler, at least 11,500 feet deep, and over 80 miles in length. A few low ridges which are parallel to the sides of the valley may possibly be the result of landslips.

5. *Aristillus.*—Under favourable conditions Lord Rosse's great telescope has shown the exterior of this magnificent crater to be scored with deep gullies radiating from its centre. Aristillus is about 34 miles wide and 10,000 feet in depth.

6. *Autolycus* is somewhat smaller than the foregoing, to which it forms a companion in accordance with what Mädler thought a well-defined relation amongst lunar craters, by which they frequently occurred in pairs, with the smaller one more usually to the south. Towards the edge this arrangement is generally rather apparent than real, and is merely a result of foreshortening.

7. *Archimedes*.—This large plain, about 50 miles in diameter, has its vast smooth interior divided by unequally bright streaks into seven distinct zones, running east and west. There is no central mountain or other obvious internal sign of former activity, but its irregular wall rises into abrupt towers, and is marked outside by decided terraces.

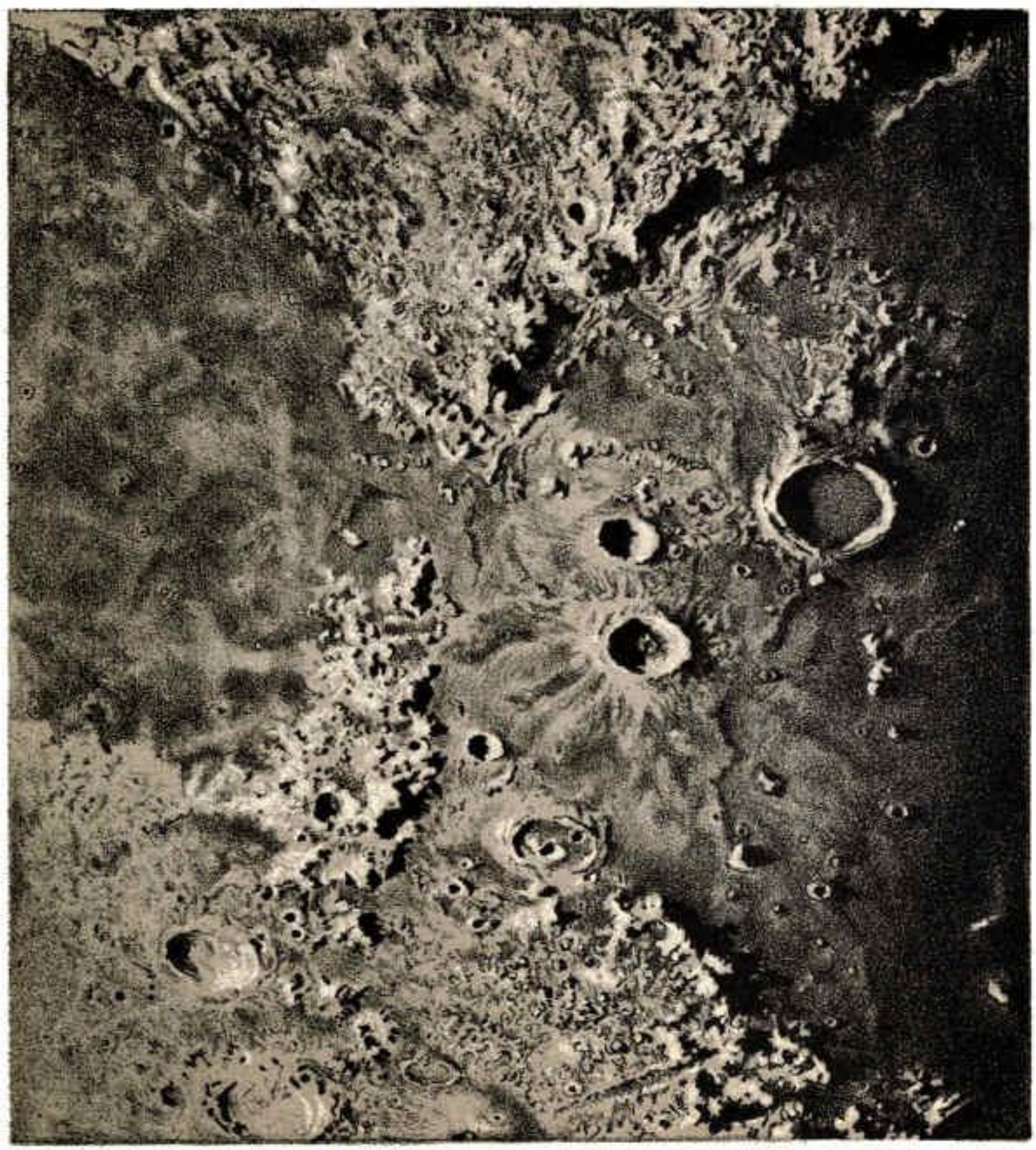

PLATE B.
PORTION OF THE MOON.
(ALPS, ARCHIMEDES, APENNINES.)
Messrs. Loewy & Puiseux.

[Pg 89]

8. *Plato.*—We have already referred to this extensive circular plain, which is noticeable with the smallest telescope. The average height of the rampart is about 3,800 feet on the eastern side; the western side is somewhat lower, but there is one peak rising to the height of nearly 7,300 feet. The plain girdled by this vast rampart is of ample proportions. It is a somewhat irregular circle, about 60 miles in diameter, and containing an area of 2,700 square miles. On its floor the shadows of the western wall are shown in Plate IX., as are also three of the small craters, of which a large number have been detected by persevering observers. The narrow sharp line leading from the crater to the left is one of those remarkable "clefts" which traverse the moon in so many directions. Another may be seen further to the left. Above Plato are several detached mountains, the loftiest of which is Pico, about 8,000 feet in height. Its long and pointed shadow would at first sight lead one to suppose that it must be very steep; but Schmidt, who specially studied the inclinations of the lunar slopes, is of opinion that it cannot be nearly so steep as many of the Swiss mountains that are frequently ascended. As many as thirty minute craters have been carefully observed on the floor of Plato, and variations have been thought by Mr. W.H. Pickering to be perceptible.

9. *Eratosthenes.*—This profound crater, upwards of 37 miles in diameter, lies at the end of the gigantic range of the Apennines. Not improbably, Eratosthenes once formed the volcanic vent for the stupendous forces that elevated the comparatively craterless peaks of these great mountains.

10. *Copernicus.*—Of all the lunar craters this is one of the grandest and best known. The region to the west is dotted over with innumerable minute craterlets. It has a central many-peaked mountain about 2,400 feet in height. There is good reason to believe that the terracing shown in its interior is mainly due to the repeated alternate rise, partial congelation, and subsequent retreat of a vast sea of lava. At full moon the crater of Copernicus is seen to be surrounded by radiating streaks.

[Pg 90]

11. *Kepler.*—Although the internal depth of this crater is scarcely less than 10,000 feet, it has but a very low surrounding wall, which is remarkable for being covered with the same glistening substance that also forms a system of bright rays not unlike those surrounding the last object.

12. *Aristarchus* is the most brilliant of the lunar craters, being specially vivid with a low power in a large telescope. So bright is it, indeed, that it has often been seen on the

dark side just after new moon, and has thus given rise to marvellous stories of active lunar volcanoes. To the south-east lies another smaller crater, Herodotus, north of which is a narrow, deep valley, nowhere more than 2-1⁄2 miles broad, which makes a remarkable zigzag. It is one of the largest of the lunar "clefts."

13. *Grimaldi* calls for notice as the darkest object of its size in the moon. Under very exceptional circumstances it has been seen with the naked eye, and as its area has been estimated at nearly 14,000 square miles, it gives an idea of how little unaided vision can discern in the moon; it must, however, be added that we always see Grimaldi considerably foreshortened.

14. The great crater *Gassendi* has been very frequently mapped on account of its elaborate system of "clefts." At its northern end it communicates with a smaller but much deeper crater, that is often filled with black shadow after the whole floor of Gassendi has been illuminated.

15. *Schickard* is one of the largest walled plains on the moon, about 134 miles in breadth. Within its vast expanse Mädler detected 23 minor craters. With regard to this object Chacornac pointed out that, owing to the curvature of the surface of the moon, a spectator at the centre of the floor "would think himself in a boundless desert," because the surrounding wall, although in one place nearly 10,000 feet high, would lie entirely beneath his horizon.

16. Close to the foregoing is *Wargentin*. There can be little doubt that this is really a huge crater almost filled with congealed lava, as there is scarcely any fall towards the interior.

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17. *Clavius*.—Near the 60th parallel of lunar south latitude lies this enormous enclosure, the area of which is not less than 16,500 square miles. Both in its interior and on its walls are many peaks and secondary craters. The telescopic view of a sunrise upon the surface of Clavius is truly said by Mädler to be indescribably magnificent. One of the peaks rises to a height of 24,000 feet above the bottom of one of the included craters. Mädler even expressed the opinion that in this wild neighbourhood there are craters so profound that no ray of sunlight ever penetrated their lowest depths, while, as if in compensation, there are peaks whose summits enjoy a mean day almost twice as long as their night.

18. If the full moon be viewed through an opera-glass or any small hand-telescope, one crater is immediately seen to be conspicuous beyond all others, by reason of the brilliant rays or streaks that radiate from it. This is the majestic *Tycho*, 17,000 feet in

depth and 50 miles in diameter (Plate X.). A peak 6,000 feet in height rises in the centre of its floor, while a series of terraces diversity its interior slopes; but it is the mysterious bright rays that chiefly surprise us. When the sun rises on Tycho, these streaks are utterly invisible; indeed, the whole object is then so obscure that it requires a practised eye to recognise Tycho amidst its mountainous surroundings. But as soon as the sun has attained a height of about 30° above its horizon, the rays emerge from their obscurity and gradually increase in brightness until the moon becomes full, when they are the most conspicuous objects on her surface. They vary in length, from a few hundred miles to two or, in one instance, nearly three thousand miles. They extend indifferently across vast plains, into the deepest craters, or over the loftiest elevations. We know of nothing on our earth to which they can be compared. As these rays are only seen about the time of full moon, their visibility obviously depends on the light falling more or less closely in the line of sight, quite regardless of the inclination of the surfaces, mountains or valleys, on which they appear. Each small portion of the surface of the streak must therefore be of a form which is symmetrical to the spectator[Pg 92] from whatever point it is seen. The sphere alone appears to fulfil this condition, and Professor Copeland therefore suggests that the material constituting the surface of the streak must be made up of a large number of more or less completely spherical globules. The streaks must represent parts of the lunar surface either pitted with minute cavities of spherical figure, or strewn over with minute transparent spheres.[8]

Near the centre of the moon's disc is a fine range of ring plains fully open to our view under all illuminations. Of these, two may be mentioned—*Alphonsus* (19), the floor of which is strangely characterised by two bright and several dark markings which cannot be explained by irregularities in the surface.—*Ptolemy* (20). Besides several small enclosed craters, its floor is crossed by numerous low ridges, visible when the sun is rising or setting.

21, 22, 23.—When the moon is five or six days old this beautiful group of three craters will be favourably placed for observation. They are named *Catharina*, *Cyrillus*, and *Theophilus*. Catharina, the most southerly of the group, is more than 16,000 feet deep, and connected with Cyrillus by a wide valley; but between Cyrillus and Theophilus there is no such connection. Indeed, Cyrillus looks as if its huge surrounding ramparts, as high as Mont Blanc, had been completely finished before the volcanic forces commenced the formation of Theophilus, the rampart of which encroaches considerably on its older neighbour. Theophilus stands as a well-defined circular crater about 64 miles in diameter, with an internal depth of 14,000 to 18,000 feet, and a beautiful central group of mountains, one-third of that height, on its floor.

Although Theophilus is the deepest crater we can see in the moon, it has suffered little or no deformation from secondary eruptions, while the floor and wall of Catharina show complete sequences of lesser craters of various sizes that have broken in upon and partly destroyed each other. In the spring of the year, when the moon is somewhat before the first quarter, this instructive group of extinct volcanoes can be seen to great advantage at a convenient hour in the evening.

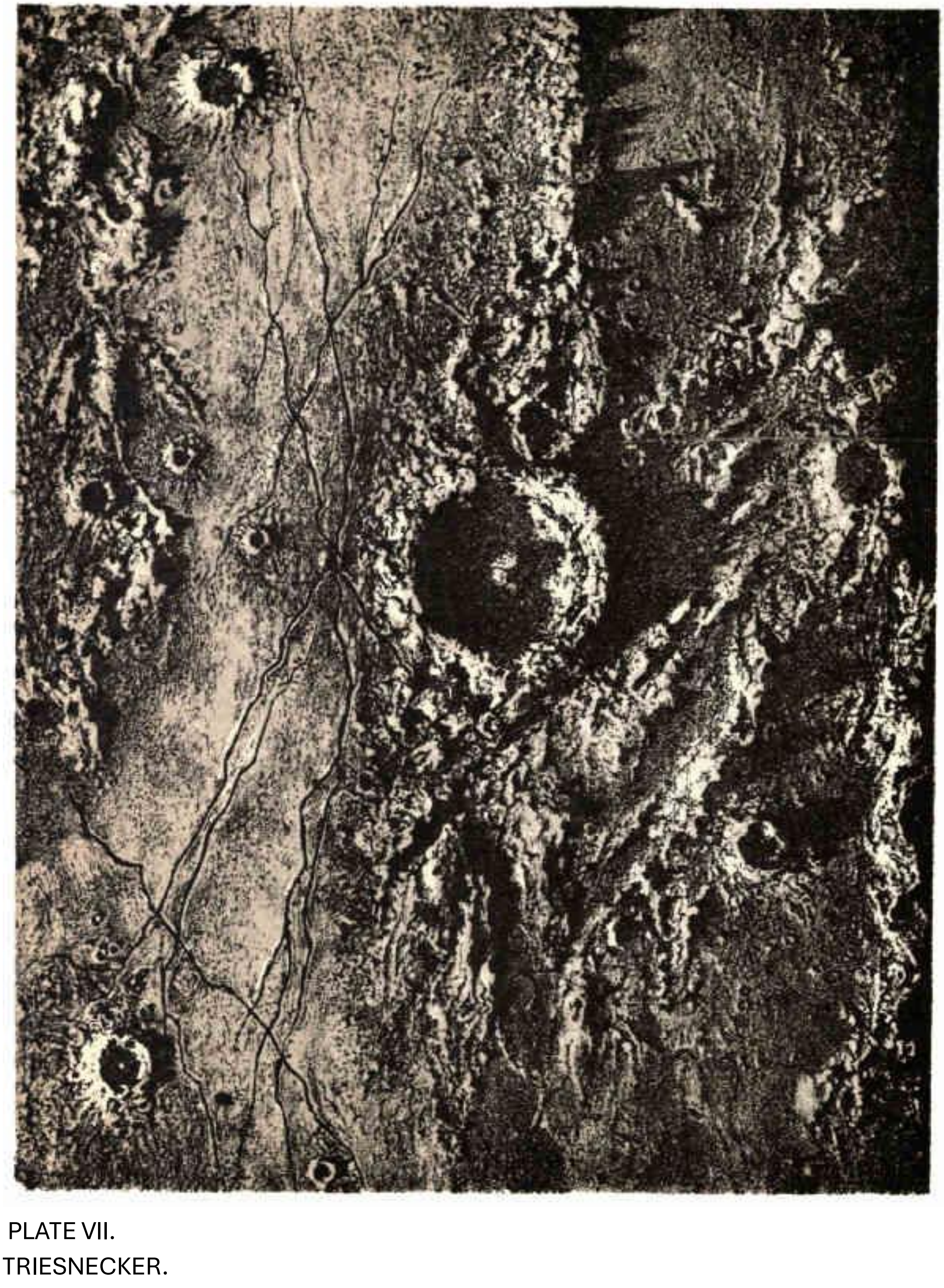

PLATE VII.
TRIESNECKER.
(AFTER NASMYTH.)

24. *Petavius* is remarkable not only for its great size, but also for the rare feature of having a double rampart. It is a beautiful object soon after new moon, or just after full moon, but disappears absolutely when the sun is more than 45° above its horizon. The crater floor is remarkably convex, culminating in a central group of hills intersected by a deep cleft.

25. *Hyginus* is a small crater near the centre of the moon's disc. One of the largest of the lunar chasms passes right through it, making an abrupt turn as it does so.

26. *Triesnecker.*—This fine crater has been already described, but is again alluded to in order to draw attention to the elaborate system of chasms so conspicuously shown in Plate VII. That these chasms are depressions is abundantly evident by the shadows inside. Very often their margins are appreciably raised. They seem to be fractures in the moon's surface.

Of the various mountains that are occasionally seen as projections on the actual edge of the moon, those called after Leibnitz (*i*) seem to be the highest. Schmidt found the highest peak to be upwards of 41,900 feet above a neighbouring valley. In comparing these altitudes with those of mountains on our earth, we must for the latter add the depth of the sea to the height of the land. Reckoned in this way, our highest mountains are still higher than any we know of in the moon.

We must now discuss the important question as to the origin of these remarkable features on the surface of the moon. We shall admit at the outset that our evidence on this subject is only indirect. To establish by unimpeachable evidence the volcanic origin of the remarkable lunar craters, it would seem almost necessary that volcanic outbursts should have been witnessed on the moon, and that such outbursts should have been seen to result in the formation of the well-known ring, with or without the mountain rising from the[Pg 94] centre. To say that nothing of the kind has ever been witnessed would be rather too emphatic a statement. On certain occasions careful observers have reported the occurrence of minute local changes on the moon. As we have already remarked, a crater named Linné, of dimensions respectable, no doubt, to a lunar inhabitant, but forming a very inconsiderable telescopic object, was thought to have undergone some change. On another occasion a minute crater was thought to have arisen near the well-known object named Hyginus. The mere enumeration of such instances gives real emphasis to the statement that there is at the present time no appreciable source of disturbance of the moon's surface. Even were these trifling cases of suspected change really established—and this is perhaps rather farther than many astronomers would be willing to go—they are still insignificant when compared with the mighty phenomena that gave rise to the host of great craters which cover so large a portion of the moon's surface.

We are led inevitably to the conclusion that our satellite must have once possessed much greater activity than it now displays. We can also give a reasonable, or, at all events, a plausible, explanation of the cessation of that activity in recent times. Let us glance at two other bodies of our system, the earth and the sun, and compare them with the moon. Of the three bodies, the sun is enormously the largest, while the moon is much less than the earth. We have also seen that though the sun must have a very high temperature, there can be no doubt that it is gradually parting with its heat. The surface of the earth, formed as it is of solid rocks and clay, or covered in great part by the vast expanse of ocean, bears but few obvious traces of a high temperature. Nevertheless, it is highly probable from ordinary volcanic phenomena that the interior of the earth still possesses a temperature of incandescence.

A large body when heated takes a longer time to cool than does a small body raised to the same temperature. A large iron casting will take days to cool; a small casting will become cold in a few hours. Whatever may have been the[Pg 95] original source of heat in our system—a question which we are not now discussing—it seems demonstrable that the different bodies were all originally heated, and have now for ages been gradually cooling. The sun is so vast that he has not yet had time to cool; the earth, of intermediate bulk, has become cold on the outside, while still retaining vast stores of internal heat; while the moon, the smallest body of all, has lost its heat to such an extent that changes of importance on its surface can no longer be originated by internal fires.

We are thus led to refer the origin of the lunar craters to some ancient epoch in the moon's history. We have no moans of knowing the remoteness of that epoch, but it is reasonable to surmise that the antiquity of the lunar volcanoes must be extremely great. At the time when the moon was sufficiently heated to originate those convulsions, of which the mighty craters are the survivals, the earth must also have been much hotter than it is at present. When the moon possessed sufficient heat for its volcanoes to be active, the earth was probably so hot that life was impossible on its surface. This supposition would point to an antiquity for the lunar craters far too great to be estimated by the centuries and the thousands of years which are adequate for such periods as those with which the history of human events is concerned. It seems not unlikely that millions of years may have elapsed since the mighty craters of Plato or of Copernicus consolidated into their present form.

We shall now attempt to account for the formation of the lunar craters. The most probable views on the subject seem to be those which have been set forth by Mr. Nasmyth, though it must be admitted that his doctrines are by no means free from difficulty. According to his theory we can explain how the rampart around the lunar crater has been formed, and how the great mountain arose which so often adorns the centre of the plain. The view in Fig. 28 contains an imaginary sketch of a volcanic vent on the moon in the days when the craters were active. The eruption is[Pg 96] here shown in the fulness of its energy, when the internal forces are hurling forth ashes or stones which fall at a considerable distance from the vent. The materials thus accumulated constitute the rampart surrounding the crater.

The second picture (Fig. 29) depicts the crater in a later stage of its history. The prodigious explosive power has now been exhausted, and has perhaps been intermitted for some time. Again, the volcano bursts into activity, but this time with only a small part of its original energy. A comparatively feeble eruption now issues from the same vent, deposits materials close around the orifice, and raises a mountain in the centre. Finally, when the activity has subsided, and the volcano is silent and still, we find the evidence of the early energy testified to by the rampart which surrounds the ancient crater, and by the mountain which adorns the interior. The flat floor which is found in some of the craters may not improbably have arisen from an outflow of lava which has afterwards consolidated. Subsequent outbreaks have also occurred in many cases.

One of the principal difficulties attending this method of accounting for the structure of a crater arises from the great size which some of these objects attain. There are ancient volcanoes on the moon forty or fifty miles in diameter; indeed, there is one well-formed ring, with a mountain rising in the centre, the diameter of which is no less than seventy-eight miles (Petavius). It seems difficult to conceive how a blowing cone at the centre could convey the materials to such a distance as the thirty-nine miles between the centre of Petavius and the rampart. The explanation is, however, facilitated when it is borne in mind that the force of gravitation is much less on the moon than on the earth.

PLATE VIII.

A NORMAL LUNAR CRATER.

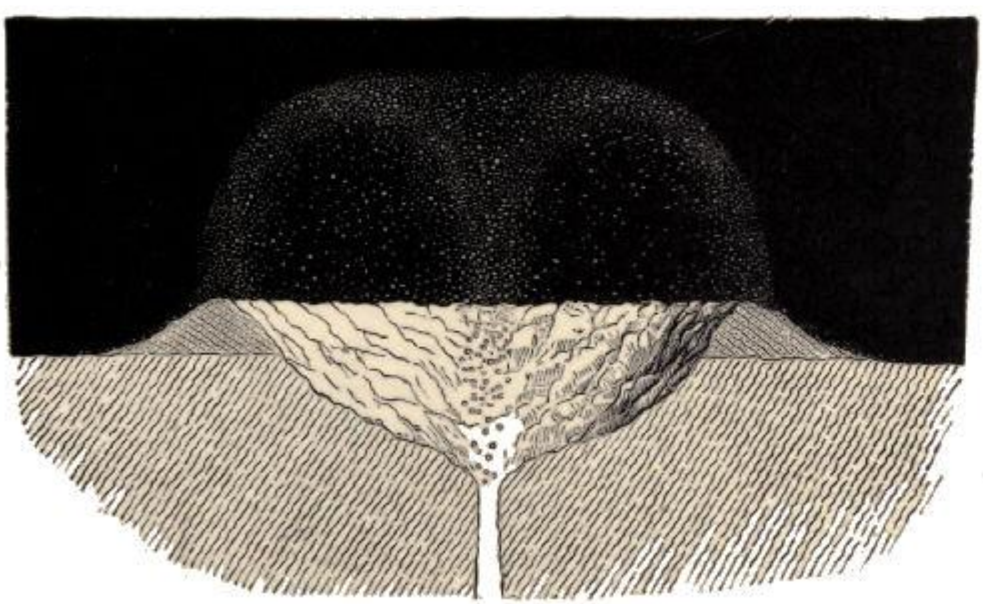

Fig. 28.—

Volcano in Activity.

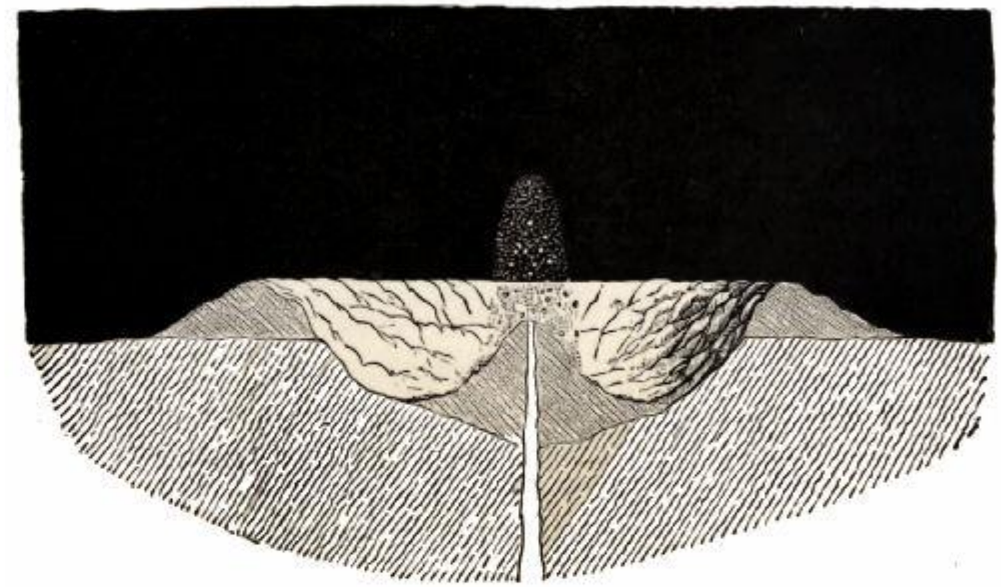

Fig. 29.—Subsequent Feeble Activity.

Have we not already seen that our satellite is so much smaller than the earth that eighty moons rolled into one would not weigh as much as the earth? On the earth an ounce weighs an ounce and a pound weighs a pound; but a weight of six ounces here would only weigh one ounce on the moon, and a weight of six pounds here would only weigh one pound on the moon. A labourer who can carry one sack of corn on the earth could, with the same exertion, carry six sacks of corn on the moon. A cricketer who can throw a ball 100 yards on the earth could with precisely the same exertion throw the same ball 600 yards on the moon. Hiawatha could shoot ten arrows into the air one[Pg 98] after the other before the first reached the ground; on the moon he might have emptied his whole quiver. The volcano, which on the moon drove projectiles to the distance of thirty-nine miles, need only possess the same explosive power as would have been sufficient to drive the missiles six or seven miles on the earth. A modern cannon properly elevated would easily achieve this feat.

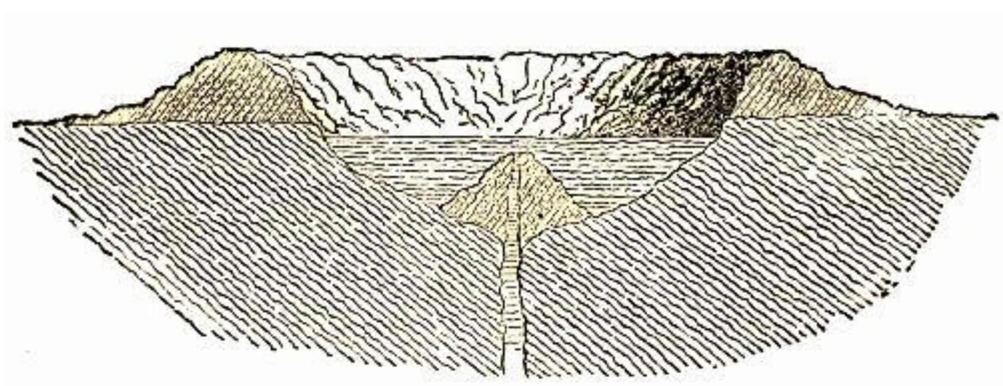

Fig. 30.—Formation of the Level Floor by Lava.

It must also be borne in mind that there are innumerable craters on the moon of the same general type but of the most varied dimensions; from a tiny telescopic object two or three miles in diameter, we can point out gradually ascending stages until we reach the mighty Petavius just considered. With regard to the smaller craters, there is obviously little or no difficulty in attributing to them a volcanic origin, and as the continuity from the smallest to the largest craters is unbroken, it seems quite reasonable to suppose that even the greatest has arisen in the same way.

It should, however, be remarked that some lunar features might be explained by actions from without rather than from within. Mr. G.K. Gilbert has marshalled the evidence in support of the belief that lunar sculptures arise from the impact of bodies falling on the moon. The Mare Imbrium, according to this view, has been the seat of a collision to which the surrounding lunar scenery is due. Mr. Gilbert explains the furrows as hewn out by mighty projectiles moving with such velocities as meteors possess.

The lunar landscapes are excessively weird and rugged.[Pg 99] They always remind us of sterile deserts, and we cannot fail to notice the absence of grassy plains or green forests such as we are familiar with on our globe. In some respects the moon is not very differently circumstanced from the earth. Like it, the moon has the pleasing alternations of day and night, though the day in the moon is as long as twenty-nine of our days, and the night of the moon is as long as twenty-nine of our nights. We are warmed by the rays of the sun; so, too, is the moon; but, whatever may be the temperature during the long day on the moon, it seems certain that the cold of the lunar night would transcend that known in the bleakest regions of our earth. The amount of heat radiated to us by the moon has been investigated by Lord Rosse, and more recently by Professor Langley. Though every point on the moon's surface is exposed to the sunlight for a fortnight without any interruption, the actual temperature to which the soil is raised cannot be a high one. The moon does not, like the earth, possess a warm blanket, in the shape of an atmosphere, which can keep in and accumulate the heat received.

Even our largest telescopes can tell nothing directly as to whether life can exist on the moon. The mammoth trees of California might be growing on the lunar mountains, and elephants might be walking about on the plains, but our telescopes could not show them. The smallest object that we can see on the moon must be about as large as a good-sized cathedral, so that organised beings resembling in size any that we are familiar with, if they existed, could not make themselves visible as telescopic objects.

We are therefore compelled to resort to indirect evidence as to whether life would be possible on the moon. We may say at once that astronomers believe that life, as we know it, could not exist. Among the necessary conditions of life, water is one of the first. Take every form of vegetable life, from the lichen which grows on the rock to the giant tree of the forest, and we find the substance of every plant contains water, and could not exist without it. Nor is water less necessary to the existence of animal life. Deprived of this element, all organic life, the life of man himself, would be inconceivable.

[Pg 100]

Unless, therefore, water be present in the moon, we shall be bound to conclude that life, as we know it, is impossible. If anyone stationed on the moon were to look at the earth through a telescope, would he be able to see any water here? Most undoubtedly he would. He would see the clouds and he would notice their incessant changes, and the clouds alone would be almost conclusive evidence of the existence of water. An astronomer on the moon would also see our oceans as coloured surfaces, remarkably contrasted with the land, and he would perhaps frequently see an image of the sun, like a brilliant star, reflected from some smooth portion of the sea. In fact, considering that much more than half of our globe is covered with oceans, and that most of the remainder is liable to be obscured by clouds, the lunar astronomer in looking at our earth would often see hardly anything but water in one form or other. Very likely he would come to the conclusion that our globe was only fitted to be a residence for amphibious animals.

But when we look at the moon with our telescopes we see no direct evidence of water. Close inspection shows that the so-called lunar seas are deserts, often marked with small craters and rocks. The telescope reveals no seas and no oceans, no lakes and no rivers. Nor is the grandeur of the moon's scenery ever impaired by clouds over her surface. Whenever the moon is above our horizon, and terrestrial clouds are out of the way, we can see the features of our satellite's surface with distinctness. There are no clouds in the moon; there are not even the mists or the vapours which invariably arise wherever water is present, and therefore astronomers have been led to the conclusion that the surface of the globe which attends the earth is a sterile and a waterless desert.

Another essential element of organic life is also absent from the moon. Our globe is surrounded with a deep clothing of air resting on the surface, and extending above our heads to the height of about 200 or 300 miles. We need hardly say how necessary air is to life, and therefore we turn with interest to the question as to whether the moon can be surrounded with an atmosphere. Let us clearly understand the problem[Pg 101] we are about to consider. Imagine that a traveller started from the earth on a journey to the moon; as he proceeded, the air would gradually become more and more rarefied, until at length, when he was a few hundred miles above the earth's surface, he would have left the last perceptible traces of the earth's envelope behind him. By the time he had passed completely through the atmosphere he would have advanced only a very small fraction of the whole journey of 240,000 miles, and there would still remain a vast void to be traversed before the moon would be reached. If the moon were enveloped in the same way as the earth, then, as the traveller approached the end of his journey, and came within a few hundred miles of the moon's surface, he would meet again with traces of an atmosphere, which would gradually increase in density until he arrived at the moon's surface. The traveller would thus have passed through one stratum of air at the beginning of his journey, and through another at the end, while the main portion of the voyage would have been through space more void than that to be found in the exhausted receiver of an air-pump.

Such would be the case if the moon were coated with an atmosphere like that surrounding our earth. But what are the facts? The traveller as he drew near the moon would seek in vain for air to breathe at all resembling ours. It is possible that close to the surface there are faint traces of some gaseous material surrounding the moon, but it can only be equal to a very small fractional part of the ample clothing which the earth now enjoys. For all purposes of respiration, as we understand the term, we may say that there is no air on the moon, and an inhabitant of our earth transferred thereto would be as certainly suffocated as he would be in the middle of space.

It may, however, be asked how we learn this. Is not air transparent, and how, therefore, could our telescopes be expected to show whether the moon really possessed such an envelope? It is by indirect, but thoroughly reliable, methods of observation that we learn the destitute condition of our satellite. There are various arguments to be adduced; but the most[Pg 102] conclusive is that obtained on the occurrence of what is called an "occultation." It sometimes happens that the moon comes directly between the earth and a star, and the temporary extinction of the latter is an "occultation." We can observe the moment when the phenomenon takes place, and the suddenness of the disappearance of the star is generally remarked. If the moon were enveloped in a copious atmosphere, the interposition of this gaseous mass by the movement of the moon would produce a gradual evanescence of the star wholly wanting the abruptness which marks the obscuration.[9]

Let us consider how we can account for the absence of an atmosphere from the moon. What we call a gas has been found by modern research to be a collection of an immense number of molecules, each of which is in exceedingly rapid motion. This motion is only pursued for a short distance in one direction before a molecule comes into collision with some other molecule, whereby the directions and velocities of the individual molecules are continually changed. There is a certain average speed for each gas which is peculiar to the molecules of that gas at a certain temperature. When several gases are mixed, as oxygen and nitrogen are in our atmosphere, the molecules of each gas continue to move with their own characteristic velocities. So far as we can estimate the temperature at the boundary of the earth's atmosphere, we may assume that the average of the velocities of the oxygen molecules there found is about a quarter of a mile per second. The velocities for nitrogen are much the same, while the average speed of a molecule of hydrogen is about one mile per second, being, in fact, by far the greatest molecular velocity possessed by any gas.

PLATE IX.
PLATO.
(AFTER NASMYTH.)

A stone thrown into the air soon regains the earth. A rifle bullet fired vertically upwards will ascend higher and higher, until at length its motion ceases, it begins to return, and falls to the ground. Let us for the moment suppose that we had a rifle of infinite strength and gunpowder of unlimited power. As we increase the charge we find that the bullet will ascend higher and higher, and each time it will take a longer period before it returns to the ground. The descent of the bullet is due to the attraction of the earth. Gravitation must necessarily act on the projectile throughout its career, and it gradually lessens the velocity, overcomes the upward motion, and brings the bullet back. It must be remembered that the efficiency of the attraction decreases when the height is increased. Consequently when the body has a prodigiously great initial velocity, in consequence of which it ascends to an enormous height, its return is retarded by a twofold cause. In the first place, the distance through which it has to be recalled is greatly increased, and in the second place the efficiency of gravitation in effecting its recall has decreased. The greater the velocity, the feebler must be the capacity of gravitation for bringing back the body. We can conceive the speed to be increased to that point at which the gravitation, constantly declining as the body ascends, is never quite able to neutralise the velocity, and hence we have the remarkable case of a body projected away never to return.

It is possible to exhibit this reasoning in a numerical form, and to show that a velocity of six or seven miles a second directed upwards would suffice to convey a body entirely away from the gravitation of the earth. This speed is far beyond the utmost limits of our artillery. It is, indeed, at least a dozen times as swift as a cannon shot; and even if we could produce it, the resistance of the air would present an insuperable difficulty. Such reflections, however, do not affect the conclusion that there is for each planet a certain specific velocity appropriate to that body, and depending solely upon its size and mass, with which we should have to discharge a projectile, in order to prevent the attraction of that body from pulling the projectile back again.

It is a simple matter of calculation to determine this "critical velocity" for any celestial body. The greater the body the greater in general must be the initial speed which will enable the projectile to forsake for ever the globe from[Pg 104] which it has been discharged. As we have already indicated, this speed is about seven miles per second on the earth. It would be three on the planet Mercury, three and a half on Mars, twenty-two on Saturn, and thirty-seven on Jupiter; while for a missile to depart from the sun without prospect of return, it must leave the brilliant surface at a speed not less than 391 miles per second.

Supposing that a quantity of free hydrogen was present in our atmosphere, its molecules would move with an average velocity of about one mile per second. It would occasionally happen by a combination of circumstances that a molecule would attain a speed which exceeded seven miles a second. If this happened on the confines of the atmosphere where it escaped collision with other molecules, the latter object would fly off into space, and would not be recaptured by the earth. By incessant repetitions of this process, in the course of countless ages, all the molecules of hydrogen gas would escape from the earth, and in this manner we may explain the fact that there is no free hydrogen present in the earth's atmosphere.[10]

The velocities which can be attained by the molecules of gases other than hydrogen are far too small to permit of their escape from the attraction of the earth. We therefore find oxygen, nitrogen, water vapour, and carbon dioxide remaining as permanent components of our air. On the other hand, the enormous mass of the sun makes the "critical velocity" at the surface of that body to be so great (391 miles per second) that not even the molecules of hydrogen can possibly emulate it. Consequently, as we have seen, hydrogen is a most important component of the sun's atmospheric envelope.

If we now apply this reasoning to the moon, the critical velocity is found by calculation to be only a mile and a half per second. This seems to be well within the maximum velocities attainable by the molecules of oxygen, nitrogen, and other gases. It therefore follows that none of these gases[Pg 105] could remain permanently to form an atmosphere at the surface of so small a body as the moon. This seems to be the reason why there are no present traces of any distinct gaseous surroundings to our satellite.

The absence of air and of water from the moon explains the sublime ruggedness of the lunar scenery. We know that on the earth the action of wind and of rain, of frost and of snow, is constantly tending to wear down our mountains and reduce their asperities. No such agents are at work on the moon. Volcanoes sculptured the surface into its present condition, and, though they have ceased to operate for ages, the traces of their handiwork seem nearly as fresh to-day as they were when the mighty fires were extinguished.

"The cloud-capped towers, the gorgeous palaces, the solemn temples" have but a brief career on earth. It is chiefly the incessant action of water and of air that makes them vanish like the "baseless fabric of a vision." On the moon these causes of disintegration and of decay are all absent, though perhaps the changes of temperature in the transition from lunar day to lunar night would be attended with expansions and contractions that might compensate in some slight degree for the absence of more potent agents of dissolution.

It seems probable that a building on the moon would remain for century after century just as it was left by the builders. There need be no glass in the windows, for there is no wind and no rain to keep out. There need not be fireplaces in the rooms, for fuel cannot burn without air. Dwellers in a lunar city would find that no dust could rise, no odours be perceived, no sounds be heard.

Man is a creature adapted for life under circumstances which are very narrowly limited. A few degrees of temperature more or less, a slight variation in the composition of air, the precise suitability of food, make all the difference between health and sickness, between life and death. Looking beyond the moon, into the length and breadth of the universe, we find countless celestial globes with every conceivable variety of temperature and of constitution. Amid this vast number of worlds with which space is tenanted, are there any inhabited by living[Pg 106] beings? To this great question science can make no response: we cannot tell. Yet it is impossible to resist a conjecture. We find our earth teeming with life in every part. We find life under the most varied conditions that can be conceived. It is met with under the burning heat of the tropics and in the everlasting frost at the poles. We find life in caves where not a ray of light ever penetrates. Nor is it wanting in the depths of the ocean, at the pressure of tons on the square inch. Whatever may be the external circumstances, Nature generally provides some form of life to which those circumstances are congenial.

It is not at all probable that among the million spheres of the universe there is a single one exactly like our earth—like it in the possession of air and of water, like it in size and in composition. It does not seem probable that a man could live for one hour on any body in the universe except the earth, or that an oak-tree could live in any other sphere for a single season. Men can dwell on the earth, and oak-trees can thrive therein, because the constitutions of the man and of the oak are specially adapted to the particular circumstances of the earth.

Could we obtain a closer view of some of the celestial bodies, we should probably find that they, too, teem with life, but with life specially adapted to the environment—life in forms strange and weird; life far stranger to us than Columbus found it to be in the New World when he first landed there. Life, it may be, stranger than ever Dante described or Doré sketched. Intelligence may also have a home among those spheres no less than on the earth. There are globes greater and globes less—atmospheres greater and atmospheres less. The truest philosophy on this subject is crystallised in the language of Tennyson:—

"This truth within thy mind rehearse,
That in a boundless universe
Is boundless better, boundless worse.

"Think you this mould of hopes and fears
Could find no statelier than his peers
In yonder hundred million spheres?"

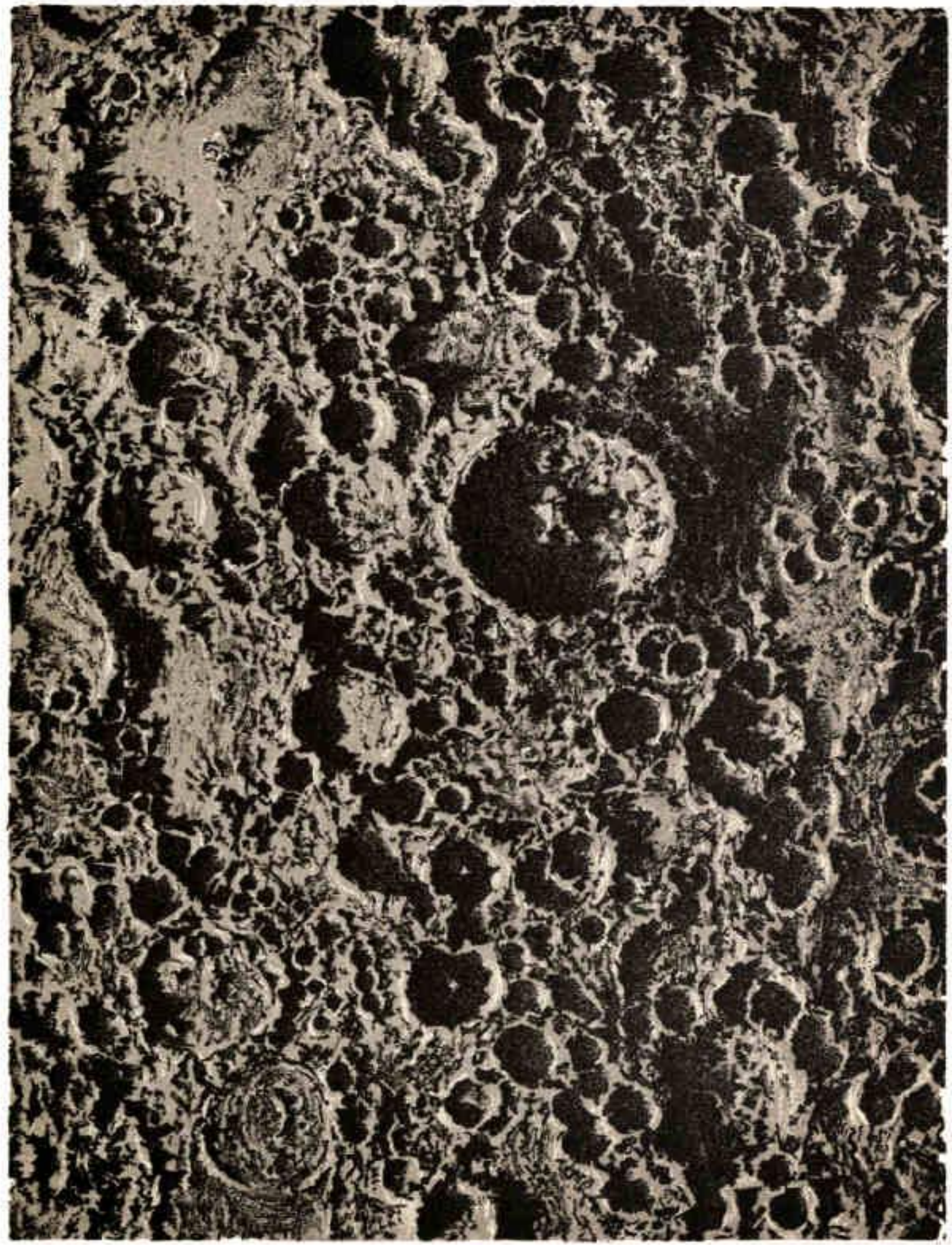

PLATE X.

TYCHO AND ITS SURROUNDINGS.

(AFTER NASMYTH.)

[Pg 107]

CHAPTER IV.

THE SOLAR SYSTEM.

Exceptional Importance of the Sun and Moon—The Course to be pursued—The Order of Distance—The Neighbouring Orbs—How are they to be discriminated?—The Planets Venus and Jupiter attract Notice by their Brilliancy—Sirius not a Neighbour—The Planets Saturn and Mercury—Telescopic Planets—The Criterion as to whether a Body is to be ranked as a Neighbour—Meaning of the word *Planet*—Uranus and Neptune—Comets—The Planets are illuminated by the Sun—The Stars are not—The Earth is really a Planet—The Four Inner Planets, Mercury, Venus, the Earth, and Mars—Velocity of the Earth—The Outer Planets, Jupiter, Saturn, Uranus, Neptune—Light and Heat received by the Planets from the Sun—Comparative Sizes of the Planets—The Minor Planets—The Planets all revolve in the same Direction—The Solar System—An Island Group in Space.

In the two preceding chapters of this work we have endeavoured to describe the heavenly bodies in the order of their relative importance to mankind. Could we doubt for a moment as to which of the many orbs in the universe should be the first to receive our attention? We do not now allude to the intrinsic significance of the sun when compared with other bodies or groups of bodies scattered through space. It may be that numerous globes rival the sun in real splendour, in bulk, and in mass. We shall, in fact, show later on in this volume that this is the case; and we shall then be in a position to indicate the true rank of the sun amid the countless hosts of heaven. But whatever may be the importance of the sun, viewed merely as one of the bodies which teem through space, there can be no hesitation in asserting how immeasurably his influence on the earth surpasses that of all other bodies in the universe together. It was therefore natural—indeed inevitable—that our first examination of the orbs of heaven should be directed to that mighty body which is the source of our life itself.

Nor could there be much hesitation as to the second step[Pg 108] which ought to be taken. The intrinsic importance of the moon, when compared with other celestial bodies, may be small; it is, indeed, as we shall afterwards see, almost infinitesimal. But in the economy of our earth the moon has played, and still plays, a part second only in importance to that of the sun himself. The moon is so close to us that her brilliant rays pale to invisibility countless orbs of a size and an intrinsic splendour incomparably greater than her own. The moon also occupies an exceptional position in the history of astronomy; for the law of gravitation, the greatest discovery that science has yet witnessed, was chiefly accomplished by observations of the moon. It was therefore natural that an early chapter in our Story of the Heavens should be devoted to a body the interest of which approximated so closely to that of the sun himself.

But the sun and the moon having been partly described (we shall afterwards have to refer to them again), some hesitation is natural in the choice of the next step. The two great luminaries being abstracted from our view, there remains no other celestial body of such exceptional interest and significance as to make it quite clear what course to pursue; we desire to unfold the story of the heavens in the most natural manner. If we made the attempt to describe the celestial bodies in the order of their actual magnitude, our ignorance must at once pronounce the task to be impossible. We cannot even make a conjecture as to which body in the heavens is to stand first on the list. Even if that mightiest body be within reach of our telescopes (in itself a highly improbable supposition), we have not the least idea in what part of the heavens it is to be sought. And even if this were possible—if we were able to arrange all the visible bodies rank by rank in the order of their magnitude and their splendour—still the scheme would be impracticable, for of most of them we know little or nothing.

We are therefore compelled to adopt a different method of procedure, and the simplest, as well as the most natural, will be to follow as far as possible the order of distance of the different bodies. We have already spoken of the moon as[Pg 109] the nearest neighbour to the earth; we shall next consider some of the other celestial bodies which are comparatively near to us; then, as the subject unfolds, we shall discuss the objects further and further away, until towards the close of the volume we shall be engaged in considering the most distant bodies in the universe which the telescope has yet revealed to us.

Even when we have decided on this principle, our course is still not free from ambiguity. Many of the bodies in the heavens are in motion, so that their relative distances from the earth are in continual change; this is, however, a difficulty which need not detain us. We shall make no attempt to adhere closely to the principle in all details. It will be sufficient if we first describe those great bodies—not a very numerous class—which are, comparatively speaking, in our vicinity, though still at varied distances; and then we shall pass on to the uncounted bodies which are separated from us by distances so vast that the imagination is baffled in the attempt to realise them.

Let us, then, scan the heavens to discover those orbs which lie in our neighbourhood. The sun has set, the moon has not risen; a cloudless sky discloses a heaven glittering with countless gems of light. Some are grouped together into well-marked constellations; others seem scattered promiscuously, with every degree of lustre, from the very brightest down to the faintest point that the eye can just glimpse. Amid all this host of objects, how are we to identify those which lie nearest to the earth? Look to the west: and there, over the spot where the departing sunbeams still linger, we often see the lovely evening star shining forth. This is the planet Venus—a beauteous orb, twin-sister to the earth. The brilliancy of this planet, its rapid changes both in position and in lustre, would suggest at once that it was much nearer to the earth than other star-like objects. This presumption has been amply confirmed by careful measurements, and therefore Venus is to be included in the list of the orbs which constitute our neighbours.

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Another conspicuous planet—almost rivalling Venus in lustre, and vastly surpassing Venus in the magnificence of its proportions and its retinue—has borne from antiquity the majestic name of Jupiter. No doubt Jupiter is much more distant from us than Venus. Indeed, he is always at least twice as far, and sometimes as much as ten times. But still we must include Jupiter among our neighbours. Compared with the host of stars which glitter on the heavens, Jupiter must be regarded as quite contiguous. The distance of the great planet requires, it is true, hundreds of millions of miles for its expression; yet, vast as is that distance, it would have to be multiplied by tens of thousands, or hundreds of thousands, before it would be long enough to span the abyss which intervenes between the earth and the nearest of the stars.

Venus and Jupiter have invited our attention by their exceptional brilliancy. We should, however, fall into error if we assumed generally that the brightest objects were those nearest to the earth. An observer unacquainted with astronomy might not improbably point to the Dog Star—or Sirius, as astronomers more generally know it—as an object whose exceptional lustre showed it to be one of our neighbours. This, however, would be a mistake. We shall afterwards have occasion to refer more particularly to this gem of our southern skies, and then it will appear that Sirius is a mighty globe far transcending our own sun in size as well as in splendour, but plunged into the depths of space to such an appalling distance that his enfeebled rays, when they reach the earth, give us the impression, not of a mighty sun, but only of a brilliant star.

The principle of selection, by which the earth's neighbours can be discriminated, will be explained presently; in the meantime, it will be sufficient to observe that our list is to be augmented first by the addition of the unique object known as Saturn, though its brightness is far surpassed by that of Sirius, as well as by a few other stars. Then we add Mars, an object which occasionally approaches so close to the earth that it shines with a fiery radiance which would[Pg 111] hardly prepare us for the truth that this planet is intrinsically one of the smallest of the celestial bodies. Besides the objects we have mentioned, the ancient astronomers had detected a fifth, known as Mercury—a planet which is usually invisible amid the light surrounding the sun. Mercury, however, occasionally wanders far enough from our luminary to be seen before sunrise or after sunset. These five—Mercury, Venus, Mars, Jupiter, and Saturn—comprised the planets known from remote antiquity.

We can, however, now extend the list somewhat further by adding to it the telescopic objects which have in modern times been found to be among our neighbours. Here we must no longer postpone the introduction of the criterion by which we can detect whether a body is near the earth or not. The brighter planets can be recognised by the steady radiance of their light as contrasted with the incessant twinkling of the stars. A little attention devoted to any of the bodies we have named will, however, point out a more definite contrast between the planets and the stars.

Observe, for instance, Jupiter, on any clear night when the heavens can be well seen, and note his position with regard to the constellations in his neighbourhood—how he is to the right of this star, or to the left of that; directly between this pair, or directly pointed to by that. We then mark down the place of Jupiter on a celestial map, or we make a sketch of the stars in the neighbourhood showing the position of the planet. After a month or two, when the observations are repeated, the place of Jupiter is to be compared again with those stars by which it was defined. It will be found that, while the stars have preserved their relative positions, the place of Jupiter has changed. Hence this body is with propriety called a *planet*, or a wanderer, because it is incessantly moving from one part of the starry heavens to another. By similar comparisons it can be shown that the other bodies we have mentioned—Venus and Mercury, Saturn and Mars—are also wanderers, and belong to that group of heavenly bodies known as planets. Here, then, we have the simple criterion by which the earth's neighbours are readily to be[Pg 112] discriminated from the stars. Each of the bodies near the earth is a planet, or a wanderer, and the mere fact that a body is a wanderer is alone sufficient to prove it to be one of the class which we are now studying.

Provided with this test, we can at once make an addition to our list of neighbours. Amid the myriad orbs which the telescope reveals, we occasionally find one which is a wanderer. Two other mighty planets, known as Uranus and Neptune, must thus be added to the five already mentioned, making in all a group of seven great planets. A vastly greater number may also be reckoned when we admit to our view bodies which not only seem to be minute telescopic objects, but really are small globes when compared with the mighty bulk of our earth. These lesser planets, to the number of more than four hundred, are also among the earth's neighbours.

We should remark that another class of heavenly bodies widely differing from the planets must also be included in our system. These are the comets, and, indeed, it may happen that one of these erratic bodies will sometimes draw nearer to the earth than even the closest approach ever made by a planet. These mysterious visitors will necessarily engage a good deal of our attention later on. For the present we confine our attention to those more substantial globes, whether large or small, which are always termed planets.

Imagine for a moment that some opaque covering could be clasped around our sun so that all his beams were extinguished. That our earth would be plunged into the darkness of midnight is of course an obvious consequence. A moment's consideration will show that the moon, shining as it does by the reflected rays of the sun, would become totally invisible. But would this extinction of the sunlight have any other effect? Would it influence the countless brilliant points that stud the heavens at midnight? Such an obscuration of the sun would indeed produce a remarkable effect on the sky at night, which a little attention would disclose. The stars, no doubt, would not exhibit the slightest change in brilliancy. Each star shines by its own light and is not indebted to the sun. The constellations would thus twinkle on as before,[Pg 113] but a wonderful change would come over the planets. Were the sun to be obscured, the planets would also disappear from view. The midnight sky would thus experience the effacement of the planets one by one, while the stars would remain unaltered. It may seem difficult to realise how the brilliancy of Venus or the lustre of Jupiter have their origin solely in the beams which fall upon these bodies from the distant sun. The evidence is, however, conclusive on the question; and it will be placed before the reader more fully when we come to discuss the several planets in detail.

Suppose that we are looking at Jupiter high in mid-heavens on a winter's night, it might be contended that, as the earth lies between Jupiter and the sun, it must be impossible for the rays of the sun to fall upon the planet. This is, perhaps, not an unnatural view for an inhabitant of this earth to adopt until he has become acquainted with the relative sizes of the various bodies concerned, and with the distances by which those bodies are separated. But the question would appear in a widely different form to an inhabitant of the planet Jupiter. If such a being were asked whether he suffered much inconvenience by the intrusion of the earth between himself and the sun, his answer would be something of this kind:—"No doubt such an event as the passage of the earth between me and the sun is possible, and has occurred on rare occasions separated by long intervals; but so far from the transit being the cause of any inconvenience, the whole earth, of which you think so much, is really so minute, that when it did come in front of the sun it was merely seen as a small telescopic point, and the amount of sunlight which it intercepted was quite inappreciable."

The fact that the planets shine by the sun's light points at once to the similarity between them and our earth. We are thus led to regard our sun as a central fervid globe associated with a number of much smaller bodies, each of which, being dark itself, is indebted to the sun both for light and for heat.

That was, indeed, a grand step in astronomy which demonstrated the nature of the solar system. The discovery that our[Pg 114] earth must be a globe isolated in space was in itself a mighty exertion of human intellect; but when it came to be recognised that this globe was but one of a whole group of similar objects, some smaller, no doubt, but others very much larger, and when it was further ascertained that these bodies were subordinated to the supreme control of the sun, we have a chain of discoveries that wrought a fundamental transformation in human knowledge.

We thus see that the sun presides over a numerous family. The members of that family are dependent upon the sun, and their dimensions are suitably proportioned to their subordinate position. Even Jupiter, the largest member of that family, does not contain one-thousandth part of the material which forms the vast bulk of the sun. Yet the bulk of Jupiter alone would exceed that of the rest of the planets were they all rolled together.

Around the central luminary in Fig. 31 we have drawn four circles in dotted lines which sufficiently illustrate the orbits in which the different bodies move. The innermost of these four paths represents the orbit of the planet Mercury. The planet moves around the sun in this path, and regains the place from which it started in eighty-eight days.

The next orbit, proceeding outwards from the sun, is that of the planet Venus, which we have already referred to as the well-known Evening Star. Venus completes the circuit of its path in 225 days. One step further from the sun and we come to the orbit of another planet. This body is almost the same size as Venus, and is therefore much larger than Mercury. The planet now under consideration accomplishes each revolution in 365 days. This period sounds familiar to our ears. It is the length of the year; and the planet is the earth on which we stand. There is an impressive way in which to realise the length of the road along which the earth has to travel in each annual journey. The circumference of a circle is about three and one-seventh times the diameter of the same figure; so that taking the distance from the earth to the centre of the sun as 92,900,000 miles, the diameter of the circle which the earth describes around the sun will be 185,800,000 miles, and consequently[Pg 115] the circumference of the mighty circle in which the earth moves round the sun is fully 583,000,000 miles. The earth has to travel this distance every year. It is merely a sum in division to find how far we have to move each second in order to accomplish this long journey in a twelvemonth. It will appear that the earth must actually complete eighteen miles every second, as otherwise it would not finish its journey within the allotted time.

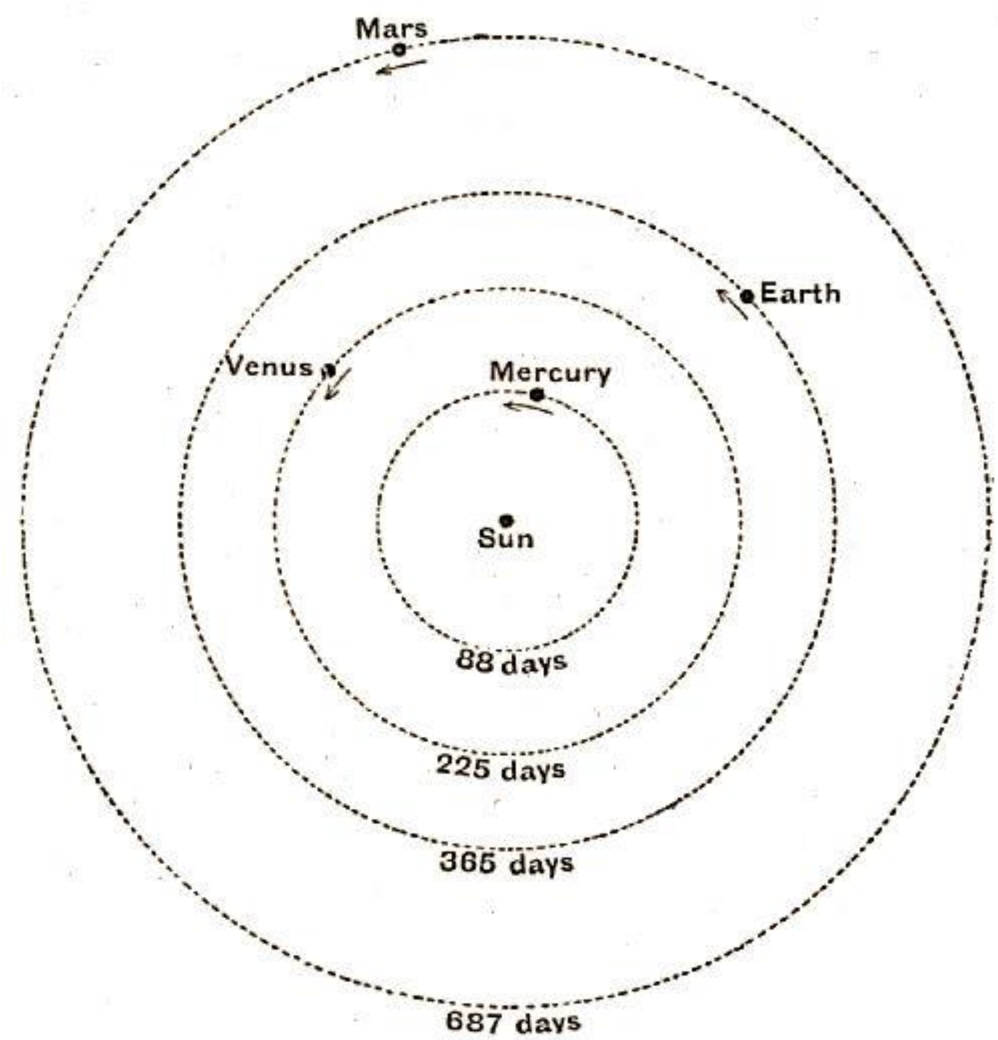

Fig. 31.—The Orbits of the Four Interior Planets.

Pause for a moment to think what a velocity of eighteen miles a second really implies. Can we realise a speed so tremendous? Let us compare it with our ordinary types of rapid movement. Look at that express train how it crashes under the bridge, how, in another moment, it is lost to view! Can any velocity be greater than that? Let us try it by figures. The train moves a mile a minute; multiply that velocity by eighteen and it becomes eighteen miles a[Pg 116] *minute*, but we must further multiply it by sixty to make it eighteen miles a *second*. The velocity of the express train is not even the thousandth part of the velocity of the earth. Let us take another illustration. We stand at the rifle ranges to see a rifle fired at a target 1,000 feet away, and we find that a second or two is sufficient to carry the bullet over that distance. The earth moves nearly one hundred times as fast as the rifle bullet.

Fig. 32.—The Earth's Movement.

Viewed in another way, the stupendous speed of the earth does not seem immoderate. The earth is a mighty globe, so great indeed that even when moving at this speed it takes almost eight minutes to pass over its own diameter. If a steamer required eight minutes to traverse a distance equal to its own length, its pace would be less than a mile an hour. To illustrate this method of considering the subject, we show here a view of the progress made by the earth (Fig. 32). The distance between the centres of these circles is about six times the diameter; and, accordingly, if they be taken to represent the earth, the time required to pass from one position to the other is about forty-eight minutes.

Outside the path of the earth, we come to the orbit of the fourth planet, Mars, which requires 687 days, or nearly two years, to complete its circuit round the sun. With our arrival at Mars we have gained the limit to the inner portion of the solar system.

The four planets we have mentioned form a group in themselves, distinguished by their comparative nearness to the sun. They are all bodies of moderate dimensions. Venus and the Earth are globes of about the same size. Mercury and Mars are both smaller objects which lie, so far as bulk is concerned, between the earth and the moon. The four planets which come nearest to the sun are vastly surpassed in bulk and weight by the giant bodies of our system—the[Pg 117] stately group of Jupiter and Saturn, Uranus and Neptune.

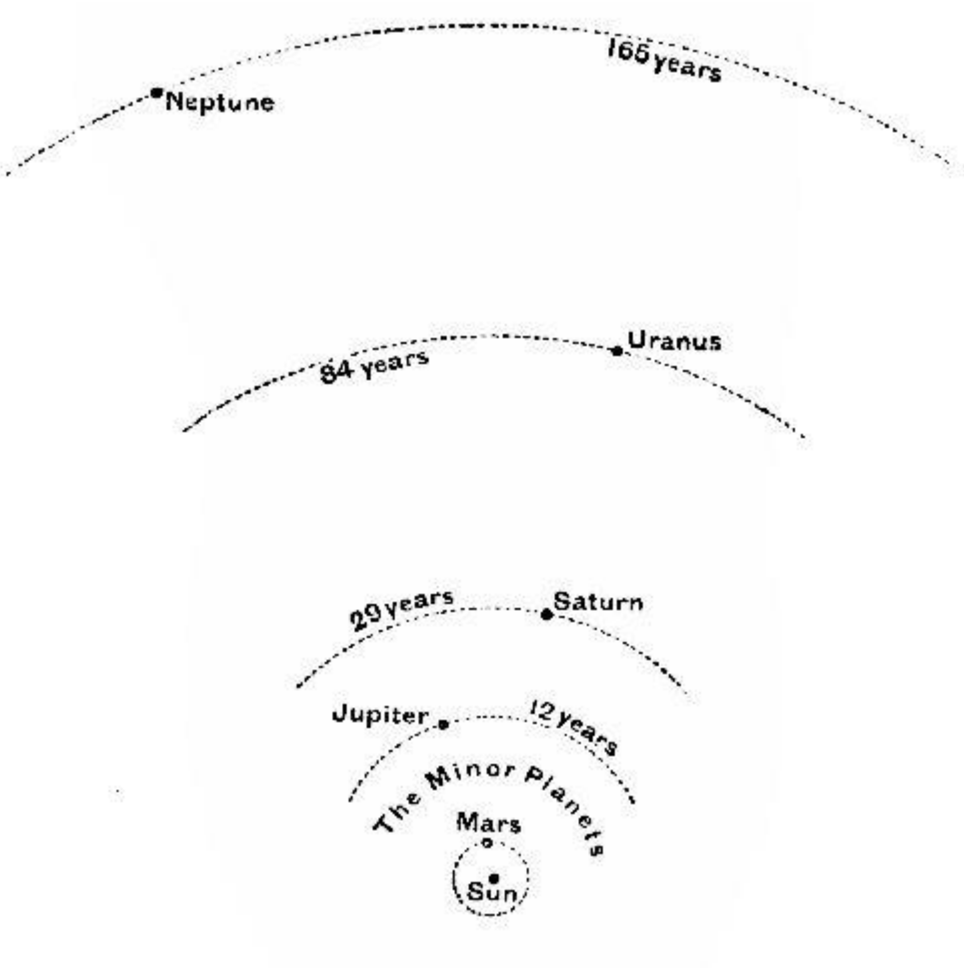

Fig. 33.—The Orbits of the Four Giant Planets.

These giant planets enjoy the sun's guidance equally with their weaker brethren. In the diagram on this page (Fig. 33) parts of the orbits of the great outer planets are represented. The sun, as before, presides at the centre, but the inner planets would on this scale be so close to the sun that it is only possible to represent the orbit of Mars. After the orbit of Mars comes a considerable interval, not, however, devoid of planetary activity, and then follow the orbits of Jupiter and Saturn; further still, we have Uranus, a great globe on the verge of unassisted vision; and, lastly, the whole system is bounded by the grand orbit of Neptune—a planet of which we shall have a marvellous story to narrate.

The various circles in Fig. 34 show the apparent sizes of the sun as seen from the different planets. Taking the circle corresponding to the earth to represent the amount[Pg 118] of heat and light which the earth derives from the sun then the other circles indicate the heat and the light enjoyed by the corresponding planets. The next outer planet to the earth is Mars, whose share of solar blessings is not so very inferior to that of the earth; but we fail to see how bodies so remote as Jupiter or Saturn can enjoy climates at all comparable with those of the planets which are more favourably situated.

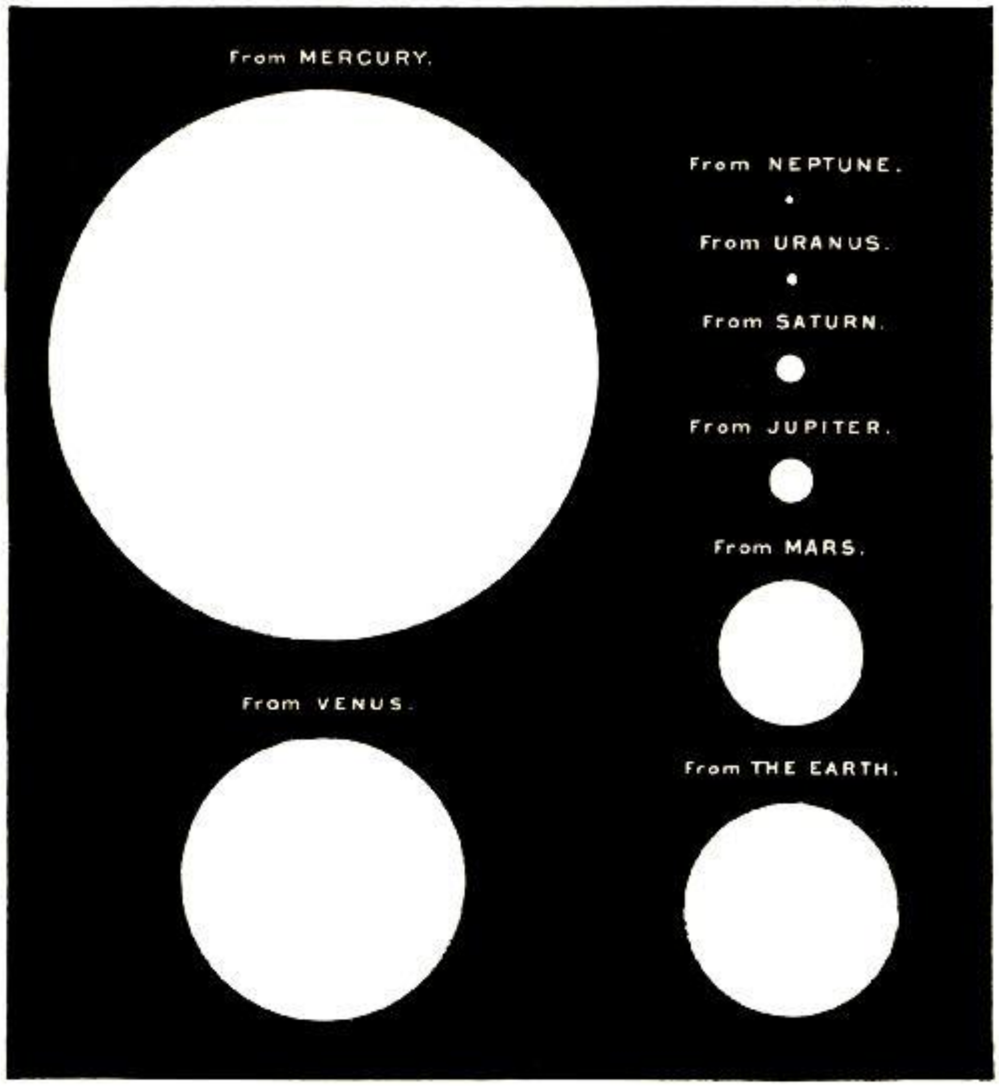

Fig. 34.—Comparative Apparent Size of the Sun as seen from the Various Planets.

Fig. 35 shows a picture of the whole family of planets[Pg 119] surrounding the sun—represented on the same scale, so as to exhibit their comparative sizes. Measured by bulk, Jupiter is more than 1,200 times as great as the earth, so that it would take at least 1,200 earths rolled into one to form a globe equal to the globe of Jupiter. Measured by weight, the disparity between the earth and Jupiter, though still enormous, is not quite so great; but this is a matter to be discussed more fully in a later chapter.

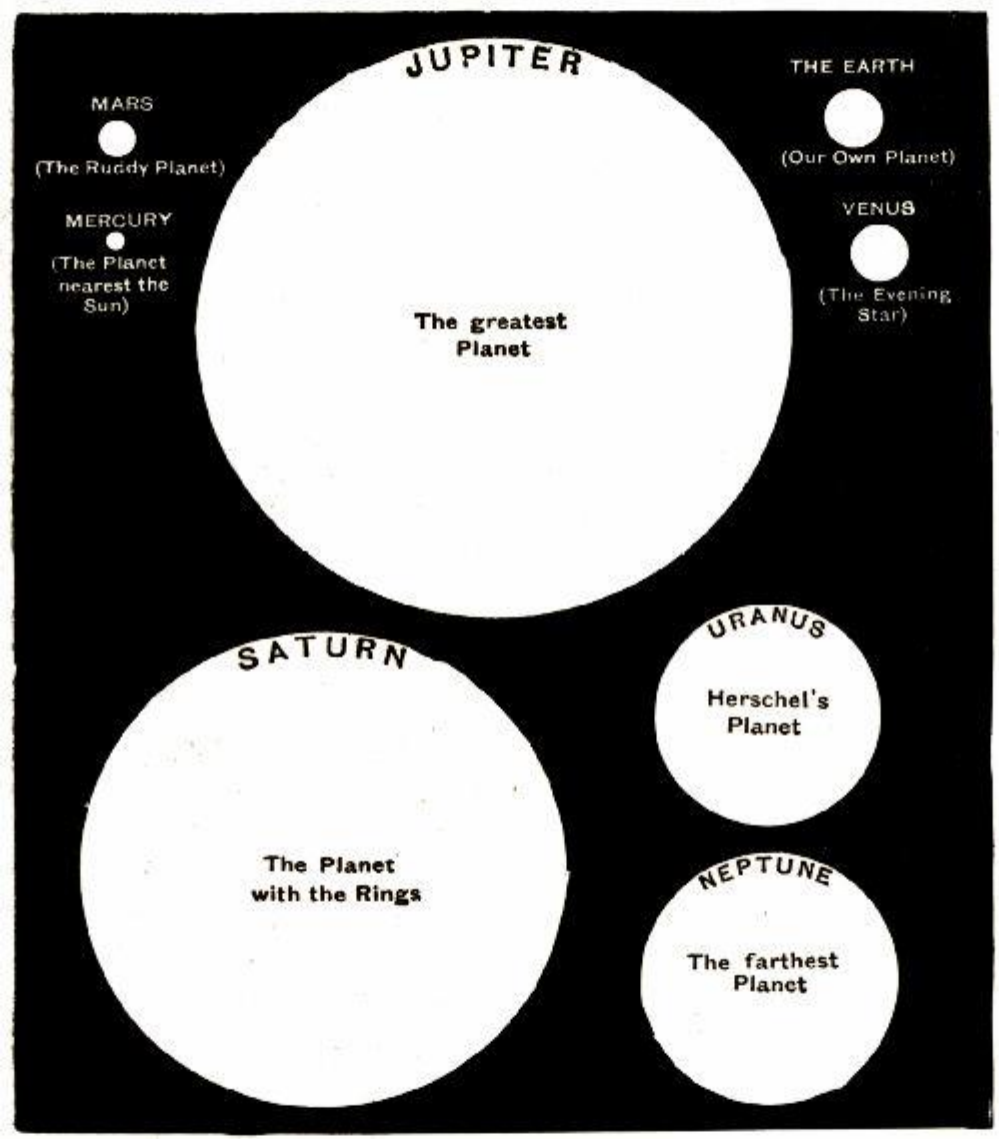

Fig. 35.—Tamaños comparativos de los planetas.

Incluso en este estudio preliminar del sistema solar nosotros[pág. 120] No debe omitirse referirse a los planetas que atraen nuestra atención, no por su volumen, sino por su multitud. En la amplia zona delimitada por el interior por la órbita de Marte y, en el exterior, junto a la órbita de Júpiter, se pensaba que era una tiempo en el que ningún planeta giraba. Investigaciones modernas han demostrado que esta región está arrendado, no por un planeta, sino por cientos. El descubrimiento de estos Planetas es una misión que ha sido asumida por varios diligentes astrónomos de la actualidad, mientras la discusión sobre sus movimientos proporciona mano de obra a otros hombres de ciencia. Encontraremos algo que aprender del estudio de estos diminutos cuerpos, y especialmente de otro pequeño planeta llamado Eros, que se encuentra más cerca de la Tierra que el límite anterior indicado. Se dedicará un capítulo a estos objetos.

Pero no pretendemos profundizar en las meras estadísticas de la sistema planetario actualmente. Si tal era nuestra intención, las mesas en el Al final del volumen se mostraría que hay abundantes materiales disponibles. Los astrónomos han hecho un inventario de cada uno de los planetas. Lo han hecho medía sus distancias, las formas de sus órbitas y las posiciones de esas órbitas, sus tiempos de revolución y, en el caso de todos los planetas más grandes, sus tamaños y sus pesos. Tales resultados son de interés por muchos propósitos. Sin embargo, son las características más generales de la ciencia que actualmente acapara nuestra atención.

En conclusión, señalemos una o dos verdades importantes con referencia a nuestro sistema planetario. Hemos visto que todos los planetas giran en Caminos casi circulares alrededor del sol. Ahora tenemos que añadir otro hecho poseyendo gran importancia. Cada uno de los planetas sigue su camino en En la misma dirección. Por tanto, ocurre que uno de esos cuerpos puede adelantar otra, pero nunca puede ocurrir que dos planetas pasen uno junto al otro como Haz los trenes en líneas ferroviarias adyacentes. Posteriormente encontraremos que todo el bienestar de nuestro sistema, más bien, su existencia continua, es dependiente de esta notable uniformidad tomada junto con otras características del sistema.

Así es nuestro sistema solar; un grupo organizado y poderoso de[Pág. 121] Planetas circulando bajo el control del sol y completamente aislada de Toda interferencia externa. Ninguna estrella, ninguna constelación tiene ninguna Influencia apreciable en nuestro sistema solar. Constituimos una pequeña isla separados de las estrellas más cercanas por distancias asombrosas. Puede ser que, así como las otras estrellas son soles, también puedan tener sistemas de planetas que circulan a su alrededor; pero de esto no sabemos nada. De la las estrellas solo podemos decir que nos aparecen como puntos de luz, y cualquier Los planetas que puedan poseer deben permanecer para siempre invisibles para nosotros, incluso si eran muchas veces más grandes que Júpiter.

No necesitamos lamentarnos de esta limitación a nuestro posible conocimiento, porque Así como encontramos en el sistema solar todo lo necesario para nuestro día a día Necesidades corporales, así encontraremos suficiente ocupación para las facultades podemos poseer en el esfuerzo por comprender esos misterios de la cielos que están al alcance de nuestra man.

[pág. 122]

CAPÍTULO V.

LA LEY DE LA GRAVITACIÓN.

Gravitación—la caída de una piedra al suelo—todos los cuerpos caen igualmente, Dieciséis pies en un segundo—¿Es esto cierto en Gran ¿Alturas?—caída de un cuerpo a una altura de un cuarto de millón Miles—Cómo Newton obtuvo una respuesta de la Luna—Su Gran Descubrimiento—Enunciado de la ley de la gravitación—Ilustraciones de la Ley—¿Cómo es posible que todos los Cuerpos del Universo no se apresuren? ¿Juntos?—El efecto del movimiento—Cómo puede ser un camino circular producido por Atracción—Relato General del Movimiento de la Luna—Es ¿La gravedad es una fuerza de gran intensidad?—Dos Pesos de 50 libras.—Dos esferas de hierro, de 53 yardas de diámetro y a una milla de distancia, atraer con una fuerza de 1 libra—Características de Gravitación—Órbitas de los planetas, no estrictamente círculos—El Descubrimientos de Kepler—Construcción de una elipse—El primero de Kepler Ley—¿Se Mueve un Planeta de forma uniforme?—Ley de los Cambios de Velocidad—Segunda ley de Kepler—La relación entre las distancias y los Periodos Periódicos—La Tercera Ley de Kepler—Las Leyes de Kepler y la Ley de la Gravedad—Movimiento en línea recta—Un cuerpo no actuado por las Fuerzas Perturbadoras se moverían en línea recta con Constante Velocidad—Aplicación a la Tierra y los Planetas—La Ley de Gravitación deducida de las Leyes de Kepler—Gravitación Universal.

Nuestra descripción de los cuerpos celestes debe sufrir un pequeño desaire interrupción, mientras ilustramos con el detalle adecuado un importante principio, conocido como la ley de la gravitación, que subyace a todo el astronomía. Por esta ley podemos explicar los movimientos de la luna alrededor La Tierra y los planetas alrededor del Sol. Así es Es nuestra responsabilidad tratar este tema antes de pasar a los más Relato particular de los planetas separados. También descubriremos que la La ley de la gravedad arroja luz muy necesaria sobre la naturaleza de la estrellas situadas a las distancias más remotas del espacio. También nos permite echar un vistazo a los paisajes del tiempo pasado, y trazar con plausibilidad, si no con certeza, ciertas fases tempranas de la historia de nuestro sistema. El sol y la luna, los planetas y los cometas, el Las estrellas y las nebulosas, todas iguales, están sujetas a esta ley universal, que ahora capta nuestra atención.

[Pág. 123]

¿Qué es más familiar que el hecho de que cuando se deja caer una piedra, es ¿caerá al suelo? Al principio nadie piensa que el asunto sea siquiera digno de comentario. La gente suele sorprenderse al ver un trozo de hierro atraído un imán. Sin embargo, la caída de una piedra al suelo es la manifestación de una fuerza tan interesante como la fuerza del magnetismo. Es la tierra que atrae la piedra, igual que el imán atrae el hierro. En cada caso La fuerza es una de atracción; pero mientras la atracción magnética es confinado a unas pocas sustancias, y es de una relación comparativamente limitada importancia, la atracción de la gravedad es significativa a lo largo de la universo.

Comencemos con unos cuantos experimentos muy sencillos sobre la fuerza de gravitación. Sujeta en la mano un pequeño trozo de plomo y luego déjalo pasar para dejarlo caer sobre un cojín. El plomo requiere un tiempo determinado para moverse desde los dedos al cojín, pero ese tiempo siempre es el mismo cuando el La altura es la misma. Toma ahora un trozo de plomo más grande y sujeta uno en cada mano a la misma altura. Si ambos se lanzan al mismo tiempo Ambos llegarán al cojín al mismo tiempo. Puede que sí se pensaba que el cuerpo pesado caería más rápido que la luz cuerpo; pero cuando se intenta el experimento, se observa que esto no es el caso. Repite el experimento con otras sustancias. Un ordinario Se encontrará que el mármol cae en el mismo tiempo que el trozo de plomo. Con Un trozo de corcho volvimos a intentar el experimento y obtenemos lo mismo resultado. Al principio parece fallar cuando comparamos una pluma con la trozo de plomo; pero eso se debe únicamente al aire, que resiste la pluma resiste más que el plomo. Si, sin embargo, la pluma es colocado sobre la parte superior de un penique, y el penique horizontal cuando si se cae, despejará el aire para apartar la pluma en su descender, y entonces la pluma caerá tan rápido como el penique, como tan rápido como la canica, o tan rápido como el plomo.

If the observer were in a gallery when trying these experiments, and if the cushion were sixteen feet below his hands, then the time the marble would take to fall through the sixteen feet would be one second. The time occupied by the cork or by the lead would be the same; and even the feather[Pg 124] itself would fall through sixteen feet in one second, if it could be screened from the interference of the air. Try this experiment where we like, in London, or in any other city, in any island or continent, on board a ship at sea, at the North Pole, or the South Pole, or the equator, it will always be found that any body, of any size or any material, will fall about sixteen feet in one second of time.

Lest any erroneous impression should arise, we may just mention that the distance traversed in one second does vary slightly at different parts of the earth, but from causes which need not at this moment detain us. We shall for the present regard sixteen feet as the distance through which any body, free from interference, would fall in one second at any part of the earth's surface. But now let us extend our view above the earth's surface, and enquire how far this law of sixteen feet in a second may find obedience elsewhere. Let us, for instance, ascend to the top of a mountain and try the experiment there. It would be found that at the top of the mountain a marble would take a little longer to fall through sixteen feet than the same marble would if let fall at its base. The difference would be very small; but yet it would be measurable, and would suffice to show that the power of the earth to pull the marble to the ground becomes somewhat weakened at a point high above the earth's surface. Whatever be the elevation to which we ascend, be it either the top of a high mountain, or the still greater altitudes that have been reached in balloon ascents, we shall never find that the tendency of bodies to fall to the ground ceases, though no doubt the higher we go the more is that tendency weakened. It would be of great interest to find how far this power of the earth to draw bodies towards it can really extend. We cannot attain more than about five or six miles above the earth's surface in a balloon; yet we want to know what would happen if we could ascend 500 miles, or 5,000 miles, or still further, into the regions of space.

Conceive that a traveller were endowed with some means of soaring aloft for miles and thousands of miles, still up[Pg 125] and up, until at length he had attained the awful height of nearly a quarter of a million of miles above the ground. Glancing down at the surface of that earth, which is at such a stupendous depth beneath, he would be able to see a wonderful bird's-eye view. He would lose, no doubt, the details of towns and villages; the features in such a landscape would be whole continents and whole oceans, in so far as the openings between the clouds would permit the earth's surface to be exposed.

At this stupendous elevation he could try one of the most interesting experiments that was ever in the power of a philosopher. He could test whether the earth's attraction was felt at such a height, and he could measure the amount of that attraction. Take for the experiment a cork, a marble, or any other object, large or small; hold it between the fingers, and let it go. Everyone knows what would happen in such a case down here; but it required Sir Isaac Newton to tell what would happen in such a case up there. Newton asserts that the power of the earth to attract bodies extends even to this great height, and that the marble would fall. This is the doctrine that we can now test. We are ready for the experiment. The marble is released, and, lo! our first exclamation is one of wonder. Instead of dropping instantly, the little object appears to remain suspended. We are on the point of exclaiming that we must have gone beyond the earth's attraction, and that Newton is wrong, when our attention is arrested; the marble is beginning to move, so slowly that at first we have to watch it carefully. But the pace gradually improves, so that the attraction is beyond all doubt, until, gradually acquiring more and more velocity, the marble speeds on its long journey of a quarter of a million of miles to the earth.

But surely, it will be said, such an experiment must be entirely impossible; and no doubt it cannot be performed in the way described. The bold idea occurred to Newton of making use of the moon itself, which is almost a quarter of a million of miles above the earth, for the purpose of answering the question. Never was our satellite put to such[Pg 126] noble use before. It is actually at each moment falling in towards the earth. We can calculate how much it is deflected towards the earth in each second, and thus obtain a measure of the earth's attractive power. From such enquiries Newton was able to learn that a body released at the distance of 240,000 miles above the surface of the earth would still be attracted by the earth, that in virtue of the attraction the body would commence to move off towards the earth—not, indeed, with the velocity with which a body falls in experiments on the surface, but with a very much lesser speed. A body dropped down from the distance of the moon would commence its long journey so slowly that a *minute*, instead of a *second*, would have elapsed before the distance of sixteen feet had been accomplished.[11]

It was by pondering on information thus won from the moon that Newton made his immortal discovery. The gravitation of the earth is a force which extends far and wide through space. The more distant the body, the weaker the gravitation becomes; here Newton found the means of determining the great problem as to the law according to which the intensity of the gravitation decreased. The information derived from the moon, that a body 240,000 miles away requires a minute to fall through a space equal to that through which it would fall in a second down here, was of paramount importance. In the first place, it shows that the attractive power of the earth, by which it draws all bodies earthwards, becomes weaker at a distance. This might, indeed, have been anticipated. It is as reasonable to suppose that as we retreated further and further into the depths of space the power of attraction should diminish, as that the lustre of light should diminish as we recede from it; and it is remarkable that the law according to which the attraction of gravitation decreases with the increase of distance is[Pg 127] precisely the same as the law according to which the brilliancy of a light decreases as its distance increases.

The law of nature, stated in its simplest form, asserts that the intensity of gravitation varies inversely as the square of the distance. Let me endeavour to elucidate this somewhat abstract statement by one or two simple illustrations. Suppose a body were raised above the surface of the earth to a height of nearly 4,000 miles, so as to be at an altitude equal to the radius of the earth. In other words, a body so situated would be twice as far from the centre of the earth as a body which lay on the surface. The law of gravitation says that the intensity of the attraction is then to be decreased to one-fourth part, so that the pull of the earth on a body 4,000 miles high is only one quarter of the pull of the earth on that body so long as it lies on the ground. We may imagine the effect of this pull to be shown in different ways. Allow the body to fall, and in the interval of one second it will only drop through four feet, a mere quarter of the distance that gravity would cause near the earth's surface.

We may consider the matter in another way by supposing that the attraction of the earth is measured by one of those little weighing machines known as a spring balance. If a weight of four pounds be hung on such a contrivance, at the earth's surface, the index of course shows a weight of four pounds; but conceive this balance, still bearing the weight appended thereto, were to be carried up and up, the *indicated* strain would become less and less, until by the time the balance reached 4,000 miles high, where it was *twice* as far away from the earth's centre as at first, the indicated strain would be reduced to the *fourth* part, and the balance would only show one pound. If we could imagine the instrument to be carried still further into the depths of space, the indication of the scale would steadily continue to decline. By the time the apparatus had reached a distance of 8,000 miles high, being then *three* times as far from the earth's centre as at first, the law of gravitation tells us that the attraction must have decreased to one-ninth part. The strain[Pg 128] thus shown on the balance would be only the ninth part of four pounds, or less than half a pound. But let the voyage be once again resumed, and let not a halt be made this time until the balance and its four-pound weight have retreated to that orbit which the moon traverses in its monthly course around the earth. The distance thus attained is about sixty times the radius of the earth, and consequently the attraction of gravitation is diminished in the proportion of one to the square of sixty; the spring will then only be strained by the inappreciable fraction of 1-3,600 part of four pounds. It therefore appears that a weight which on the earth weighed a ton and a half would, if raised 240,000 miles, weigh less than a pound. But even at this vast distance we are not to halt; imagine that we retreat still further and further; the strain shown by the balance will ever decrease, but it will still exist, no matter how far we go. Astronomy appears to teach us that the attraction of gravitation can extend, with suitably enfeebled intensity, across the most profound gulfs of space.

The principle of gravitation is of far wider scope than we have yet indicated. We have spoken merely of the attraction of the earth, and we have stated that this force extends throughout space. But the law of gravitation is not so limited. Not only does the earth attract every other body, and every other body attract the earth, but each of these bodies attracts the other; so that in its more complete shape the law of gravitation announces that "every body in the universe attracts every other body with a force which varies inversely as the square of the distance."

It is impossible for us to over-estimate the importance of this law. It supplies the clue by which we can unravel the complicated movements of the planets. It has led to marvellous discoveries, in which the law of gravitation has enabled us to anticipate the telescope, and to feel the existence of bodies before those bodies have even been seen.

An objection which may be raised at this point must first be dealt with. It seems to be, indeed, a plausible one. If the earth attracts the moon, why does not the moon tumble[Pg 129] down on the earth? If the earth is attracted by the sun, why does it not tumble into the sun? If the sun is attracted by other stars, why do they not rush together with a frightful collision? It may not unreasonably be urged that if all these bodies in the heavens are attracting each other, it would seem that they must all rush together in consequence of that attraction, and thus weld the whole material universe into a single mighty mass. We know, as a matter of fact, that these collisions do not often happen, and that there is extremely little likelihood of their taking place. We see that although our earth is said to have been attracted by the sun for countless ages, yet the earth is just as far from the sun as ever it was. Is not this in conflict with the doctrine of universal gravitation? In the early days of astronomy such objections would be regarded, and doubtless were regarded, as well-nigh insuperable; even still we occasionally hear them raised, and it is therefore the more incumbent on us to explain how it happens that the solar system has been able to escape from the catastrophe by which it seems to be threatened.

There can be no doubt that if the moon and the earth had been initially placed *at rest*, they would have been drawn together by their mutual attraction. So, too, if the system of planets surrounding the sun had been left initially *at rest* they would have dashed into the sun, and the system would have been annihilated. It is the fact that the planets are *moving*, and that the moon is *moving*, which has enabled these bodies successfully to resist the attraction in so far, at least, as that they are not drawn thereby to total destruction.

It is so desirable that the student should understand clearly how a central attraction is compatible with revolution in a nearly circular path, that we give an illustration to show how the moon pursues its monthly orbit under the guidance and the control of the attracting earth.

[Pg 130]

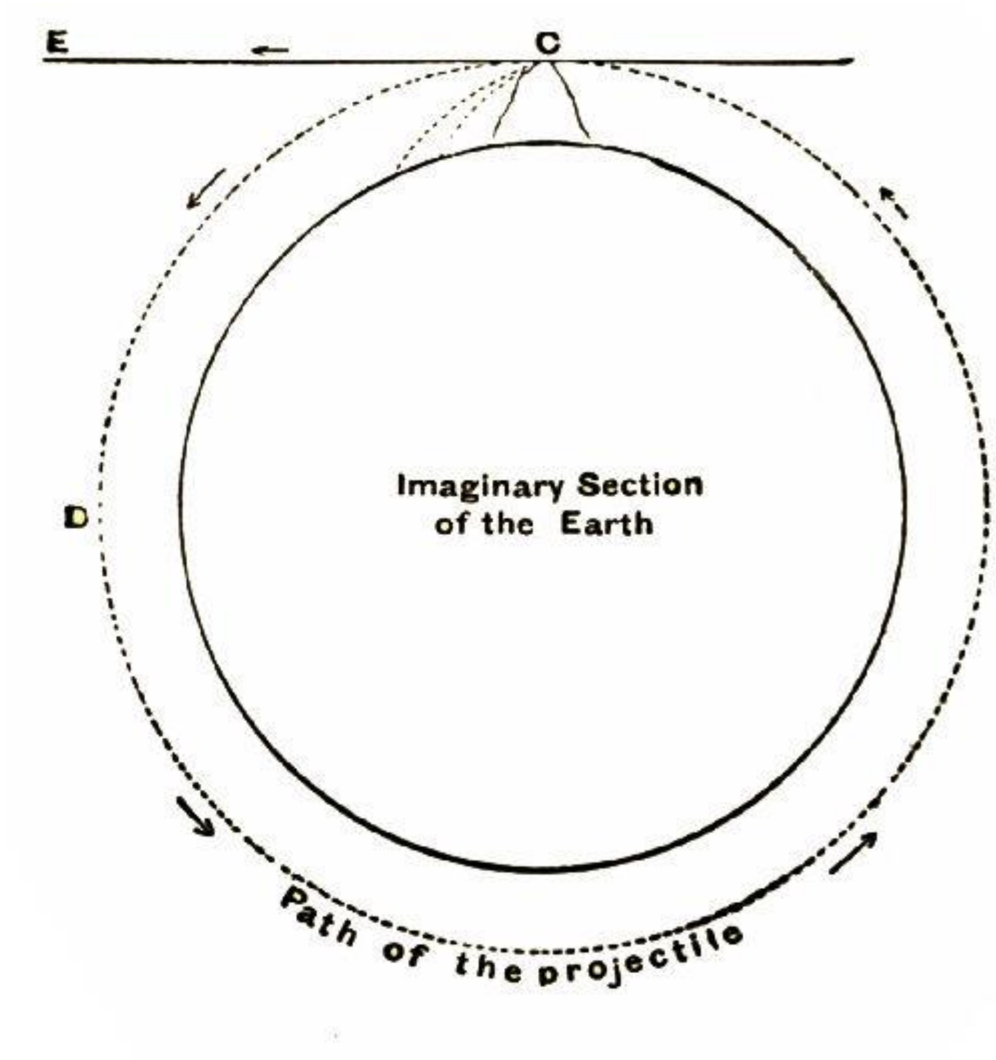

Fig. 36.—Illustration of the Moon's Motion.

The imaginary sketch in Fig. 36 denotes a section of the earth with a high mountain thereon.[12] If a cannon were stationed on the top of the mountain at C, and if the cannonball were fired off in the direction C E with a moderate charge of powder, the ball would move down along the first curved path. If it be fired a second time with a heavier charge, the path will be along the second curved line, and the ball would again fall to the ground. But let us try next time with a charge still further increased, and, indeed, with a far stronger cannon than any piece of ordnance ever yet made. The velocity of the projectile must now be assumed to be some miles per second, but we can conceive that the speed shall be so adjusted that the ball shall move along the path C D, always at the same height above the earth, though still curving, as every projectile must curve, from the horizontal line in which it moved at the first moment. Arrived at D, the ball will still be at the same height above the surface, and its velocity must be unabated. It will therefore continue in its path and move round another quadrant of the circle without getting nearer to the surface. In this manner the projectile will travel completely round the whole globe, coming back again to C and then taking another start in the same path. If we could abolish the mountain and the cannon at[Pg 131] the top, we should have a body revolving for ever around the earth in consequence of the attraction of gravitation.

Make now a bold stretch of the imagination. Conceive a terrific cannon capable of receiving a round bullet not less than 2,000 miles in diameter. Discharge this enormous bullet with a velocity of about 3,000 feet per second, which is two or three times as great as the velocity actually attainable in modern artillery. Let this notable bullet be fired horizontally from some station nearly a quarter of a million miles above the surface of the earth. That fearful missile would sweep right round the earth in a nearly circular orbit, and return to where it started in about four weeks. It would then commence another revolution, four weeks more would find it again at the starting point, and this motion would go on for ages.

Do not suppose that we are entirely romancing. We cannot indeed show the cannon, but we can point to a great projectile. We see it every month; it is the beautiful moon herself. No one asserts that the moon was ever shot from such a cannon; but it must be admitted that she moves as if she had been. In a later chapter we shall enquire into the history of the moon, and show how she came to revolve in this wonderful manner.

As with the moon around the earth, so with the earth around the sun. The illustration shows that a circular or nearly circular motion harmonises with the conception of the law of universal gravitation.

We are accustomed to regard gravitation as a force of stupendous magnitude. Does not gravitation control the moon in its revolution around the earth? Is not even the mighty earth itself retained in its path around the sun by the surpassing power of the sun's attraction? No doubt the actual force which keeps the earth in its path, as well as that which retains the moon in our neighbourhood, is of vast intensity, but that is because gravitation is in such cases associated with bodies of enormous mass. No one can deny that all bodies accessible to our observation appear to attract each other in accordance with the law of gravitation; but[Pg 132] it must be confessed that, unless one or both of the attracting bodies is of gigantic dimensions, the intensity is almost immeasurably small.

Let us attempt to illustrate how feeble is the gravitation between masses of easily manageable dimensions. Take, for instance, two iron weights, each weighing about 50lb., and separated by a distance of one foot from centre to centre. There is a certain attraction of gravitation between these weights. The two weights are drawn together, yet they do not move. The attraction between them, though it certainly exists, is an extremely minute force, not at all comparable as to intensity with magnetic attraction. Everyone knows that a magnet will draw a piece of iron with considerable vigour, but the intensity of gravitation is very much less on masses of equal amount. The attraction between these two 50lb. weights is less than the ten-millionth part of a single pound. Such a force is utterly infinitesimal in comparison with the friction between the weights and the table on which they stand, and hence there is no response to the attraction by even the slightest movement. Yet, if we can conceive each of these weights mounted on wheels absolutely devoid of friction, and running on absolutely perfect horizontal rails, then there is no doubt that the bodies would slowly commence to draw together, and in the course of time would arrive in actual contact.

If we desire to conceive gravitation as a force of measurable intensity, we must employ masses immensely more ponderous than those 50lb. weights. Imagine a pair of globes, each composed of 417,000 tons of cast iron, and each, if solid, being about 53 yards in diameter. Imagine these globes placed at a distance of one mile apart. Each globe attracts the other by the force of gravitation. It does not matter that buildings and obstacles of every description intervene; gravitation will pass through such impediments as easily as light passes through glass. No screen can be devised dense enough to intercept the passage of this force. Each of these iron globes will therefore under all circumstances attract the other; but, notwithstanding their ample[Pg 133] proportions, the intensity of that attraction is still very small, though appreciable. The attraction between these two globes is a force no greater than the pressure exerted by a single pound weight. A child could hold back one of these massive globes from its attraction by the other. Suppose that all was clear, and that friction could be so neutralised as to permit the globes to follow the impulse of their mutual attractions. The two globes will then commence to approach, but the masses are so large, while the attraction is so small, that the speed will be accelerated very slowly. A microscope would be necessary to show when the motion has actually commenced. An hour and a half must elapse before the distance is diminished by a single foot; and although the pace improves subsequently, yet three or four days must elapse before the two globes will come together.

The most remarkable characteristic of the force of gravitation must be here specially alluded to. The intensity appears to depend only on the quantity of matter in the bodies, and not at all on the nature of the substances of which these bodies are composed. We have described the two globes as made of cast iron, but if either or both were composed of lead or copper, of wood or stone, of air or water, the attractive power would still be the same, provided only that the masses remain unaltered. In this we observe a profound difference between the attraction of gravitation and magnetic attraction. In the latter case the attraction is not perceptible at all in the great majority of substances, and is only considerable in the case of iron.

In our account of the solar system we have represented the moon as revolving around the earth in a *nearly* circular path, and the planets as revolving around the sun in orbits which are also approximately circular. It is now our duty to give a more minute description of these remarkable paths; and, instead of dismissing them as being *nearly* circles, we must ascertain precisely in what respects they differ therefrom.

If a planet revolved around the sun in a truly circular path, of which the sun was always at the centre, it is[Pg 134] then obvious that the distance from the sun to the planet, being always equal to the radius of the circle, must be of constant magnitude. Now, there can be no doubt that the distance from the sun to each planet is approximately constant; but when accurate observations are made, it becomes clear that the distance is not absolutely so. The variations in distance may amount to many millions of miles, but, even in extreme cases, the variation in the distance of the planet is only a small fraction—usually a very small fraction—of the total amount of that distance. The circumstances vary in the case of each of the planets. The orbit of the earth itself is such that the distance from the earth to the sun departs but little from its mean value. Venus makes even a closer approach to perfectly circular movement; while, on the other hand, the path of Mars, and much more the path of Mercury, show considerable relative fluctuations in the distance from the planet to the sun.

It has often been noticed that many of the great discoveries in science have their origin in the nice observation and explanation of minute departures from some law approximately true. We have in this department of astronomy an excellent illustration of this principle. The orbits of the planets are nearly circles, but they are not exactly circles. Now, why is this? There must be some natural reason. That reason has been ascertained, and it has led to several of the grandest discoveries that the mind of man has ever achieved in the realms of Nature.

In the first place, let us see the inferences to be drawn from the fact that the distance of a planet from the sun is not constant. The motion in a circle is one of such beauty and simplicity that we are reluctant to abandon it, unless the necessity for doing so be made clearly apparent. Can we not devise any way by which the circular motion might be preserved, and yet be compatible with the fluctuations in the distance from the planet to the sun? This is clearly impossible with the sun at the centre of the circle. But suppose the sun did not occupy the centre, while the planet, as before, revolved around the sun. The distance between the two[Pg 135] bodies would then necessarily fluctuate. The more eccentric the position of the sun, the larger would be the proportionate variation in the distance of the planet when at the different parts of its orbit. It might further be supposed that by placing a series of circles around the sun the various planetary orbits could be accounted for. The centre of the circle belonging to Venus is to coincide very nearly with the centre of the sun, and the centres of the orbits of all the other planets are to be placed at such suitable distances from the sun as will render a satisfactory explanation of the gradual increase and decrease of the distance between the two bodies.

There can be no doubt that the movements of the moon and of the planets would be, to a large extent, explained by such a system of circular orbits; but the spirit of astronomical enquiry is not satisfied with approximate results. Again and again the planets are observed, and again and again the observations are compared with the places which the planets would occupy if they moved in accordance with the system here indicated. The centres of the circles are moved hither and thither, their radii are adjusted with greater care; but it is all of no avail. The observations of the planets are minutely examined to see if they can be in error; but of errors there are none at all sufficient to account for the discrepancies. The conclusion is thus inevitable—astronomers are forced to abandon the circular motion, which was thought to possess such unrivalled symmetry and beauty, and are compelled to admit that the orbits of the planets are not circular.

Then if these orbits be not circles, what are they? Such was the great problem which Kepler proposed to solve, and which, to his immortal glory, he succeeded in solving and in proving to demonstration. The great discovery of the true shape of the planetary orbits stands out as one of the most conspicuous events in the history of astronomy. It may, in fact, be doubted whether any other discovery in the whole range of science has led to results of such far-reaching interest.

We must here adventure for a while into the field of science known as geometry, and study therein the nature of[Pg 136] that curve which the discovery of Kepler has raised to such unparalleled importance. The subject, no doubt, is a difficult one, and to pursue it with any detail would involve us in many abstruse calculations which would be out of place in this volume; but a general sketch of the subject is indispensable, and we must attempt to render it such justice as may be compatible with our limits.

The curve which represents with perfect fidelity the movements of a planet in its revolution around the sun belongs to that well-known group of curves which mathematicians describe as the conic sections. The particular form of conic section which denotes the orbit of a planet is known by the name of the *ellipse*: it is spoken of somewhat less accurately as an oval. The ellipse is a curve which can be readily constructed. There is no simpler method of doing so than that which is familiar to draughtsmen, and which we shall here briefly describe.

We represent on the next page (Fig. 37) two pins passing through a sheet of paper. A loop of twine passes over the two pins in the manner here indicated, and is stretched by the point of a pencil. With a little care the pencil can be guided so as to keep the string stretched, and its point will then describe a curve completely round the pins, returning to the point from which it started. We thus produce that celebrated geometrical figure which is called an ellipse.

It will be instructive to draw a number of ellipses, varying in each case the circumstances under which they are formed. If, for instance, the pins remain placed as before, while the length of the loop is increased, so that the pencil is farther away from the pins, then it will be observed that the ellipse has lost some of its elongation, and approaches more closely to a circle. On the other hand, if the length of the cord in the loop be lessened, while the pins remain as before, the ellipse will be found more oval, or, as a mathematician would say, its *eccentricity* is increased. It is also useful to study the changes which the form of the ellipse undergoes when one of the pins is altered, while the length of the loop remains unchanged. If the two pins be brought[Pg 137] nearer together the eccentricity will decrease, and the ellipse will approximate more closely to the shape of a circle. If the pins be separated more widely the eccentricity of the ellipse will be increased. That the circle is an extreme form of ellipse will be evident, if we suppose the two pins to draw in so close together that they become coincident; the point will then simply trace out a circle as the pencil moves round the figure.

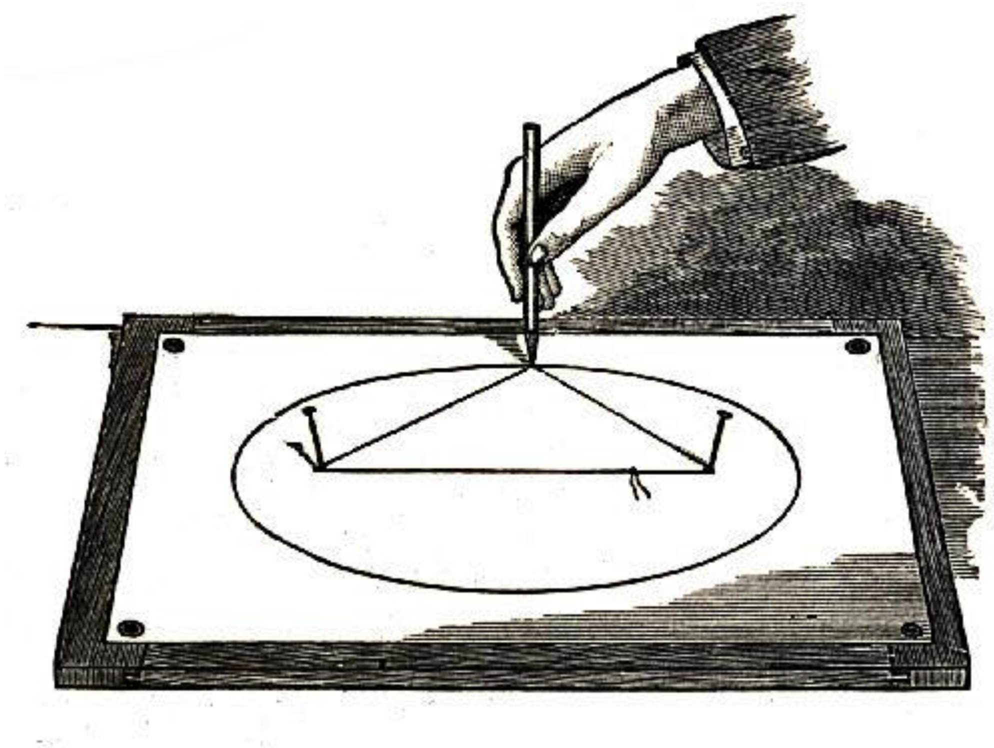

Fig. 37.—Drawing an Ellipse.

The points marked by the pins obviously possess very remarkable relations with respect to the curve. Each one is called a *focus*, and an ellipse can only have one pair of foci. In other words, there is but a single pair of positions possible for the two pins, when an ellipse of specified size, shape, and position is to be constructed.

The ellipse differs principally from a circle in the circumstance that it possesses variety of form. We can have large and small ellipses just as we can have large and small circles, but we can also have ellipses of greater or less eccentricity. If the ellipse has not the perfect simplicity of the circle it has, at least, the charm of variety which the circle has not. The oval curve has also the beauty derived from an outline of perfect grace and an association with ennobling conceptions.

The ancient geometricians had studied the ellipse: they had noticed its foci; they were acquainted with its geometrical relations; and thus Kepler was familiar with the ellipse at the time when he undertook his celebrated researches on the movements of the planets. He had found, as we have already indicated, that the movements of the planets could not be reconciled with circular orbits. What shape of orbit should next be tried? The ellipse was ready to hand, its properties were known, and the comparison could be made; memorable, indeed, was the consequence of this comparison. Kepler found that the movement of the planets could be explained, by supposing that the path in which each one revolved was an ellipse. This in itself was a discovery of the most commanding importance. On the one hand it reduced to order the movements of the great globes which circulate round the sun; while on the other, it took that beautiful class of curves which had exercised the geometrical talents of the ancients, and assigned to them the dignity of defining the highways of the universe.

But we have as yet only partly enunciated the first discovery of Kepler. We have seen that a planet revolves in an ellipse around the sun, and that the sun is, therefore, at some point in the interior of the ellipse—but at what point? Interesting, indeed, is the answer to this question. We have pointed out how the foci possess a geometrical significance which no other points enjoy. Kepler showed that the sun must be situated in one of the foci of the ellipse in which each planet revolves. We thus enunciate the first law of planetary motion in the following words:—

Each planet revolves around the sun in an elliptic path, having the sun at one of the foci.

We are now enabled to form a clear picture of the orbits of the planets, be they ever so numerous, as they revolve around the sun. In the first place, we observe that the ellipse is a plane curve; that is to say, each planet must, in the course of its long journey, confine its movements to one plane. Each planet has thus a certain plane appropriated to it. It is true that all these planes are very nearly coincident,[Pg 139] at least in so far as the great planets are concerned; but still they are distinct, and the only feature in which they all agree is that each one of them passes through the sun. All the elliptic orbits of the planets have one focus in common, and that focus lies at the centre of the sun.

It is well to illustrate this remarkable law by considering the circumstances of two or three different planets. Take first the case of the earth, the path of which, though really an ellipse, is very nearly circular. In fact, if it were drawn accurately to scale on a sheet of paper, the difference between the elliptic orbit and the circle would hardly be detected without careful measurement. In the case of Venus the ellipse is still more nearly a circle, and the two foci of the ellipse are very nearly coincident with the centre of the circle. On the other hand, in the case of Mercury, we have an ellipse which departs from the circle to a very marked extent, while in the orbits of some of the minor planets the eccentricity is still greater. It is extremely remarkable that every planet, no matter how far from the sun, should be found to move in an ellipse of some shape or other. We shall presently show that necessity compels each planet to pursue an elliptic path, and that no other form of path is possible.

Started on its elliptic path, the planet pursues its stately course, and after a certain duration, known as the *periodic time*, regains the position from which its departure was taken. Again the planet traces out anew the same elliptic path, and thus, revolution after revolution, an identical track is traversed around the sun. Let us now attempt to follow the body in its course, and observe the history of its motion during the time requisite for the completion of one of its circuits. The dimensions of a planetary orbit are so stupendous that the planet must run its course very rapidly in order to finish the journey within the allotted time. The earth, as we have already seen, has to move eighteen miles a second to accomplish one of its voyages round the sun in the lapse of 365-1⁄4 days. The question then arises as to whether the rate at which a planet moves is uniform or not. Does the earth, for instance, actually move at all times with the velocity of[Pg 140] eighteen miles a second, or does our planet sometimes move more rapidly and sometimes more slowly, so that the average of eighteen miles a second is still maintained? This is a question of very great importance, and we are able to answer it in the clearest and most emphatic manner. The velocity of a planet is *not* uniform, and the variations of that velocity can be explained by the adjoining figure (Fig. 38).

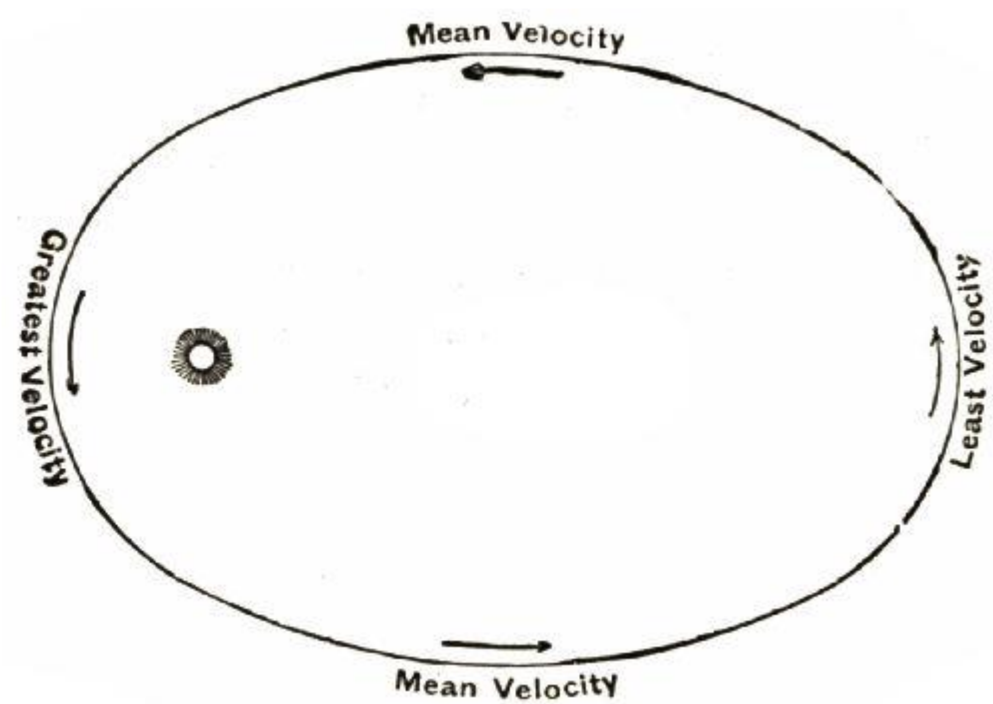

Fig. 38.—Varying Velocity of Elliptic Motion.

Let us first of all imagine the planet to be situated at that part of its path most distant from the sun towards the right of the figure. In this position the body's velocity is at its lowest; as the planet begins to approach the sun the speed gradually improves until it attains its mean value. After this point has been passed, and the planet is now rapidly hurrying on towards the sun, the velocity with which it moves becomes gradually greater and greater, until at length, as it dashes round the sun, its speed attains a maximum. After passing the sun, the distance of the planet from the luminary increases, and the velocity of the motion begins to abate; gradually it declines until the mean value is again reached, and then it falls still lower, until the body recedes to its greatest distance from the sun, by which time the velocity has abated to the value from which we supposed it to commence. We thus observe that the nearer the planet is to the sun the quicker[Pg 141] it moves. We can, however, give numerical definiteness to the principle according to which the velocity of the planet varies. The adjoining figure (Fig. 39) shows a planetary orbit, with, of course, the sun at the focus S. We have taken two portions, A B and C D, round the ellipse, and joined their extremities to the focus. Kepler's second law may be stated in these words:—

"*Every planet moves round the sun with such a velocity at every point, that a straight line drawn from it to the sun passes over equal areas in equal times.*"

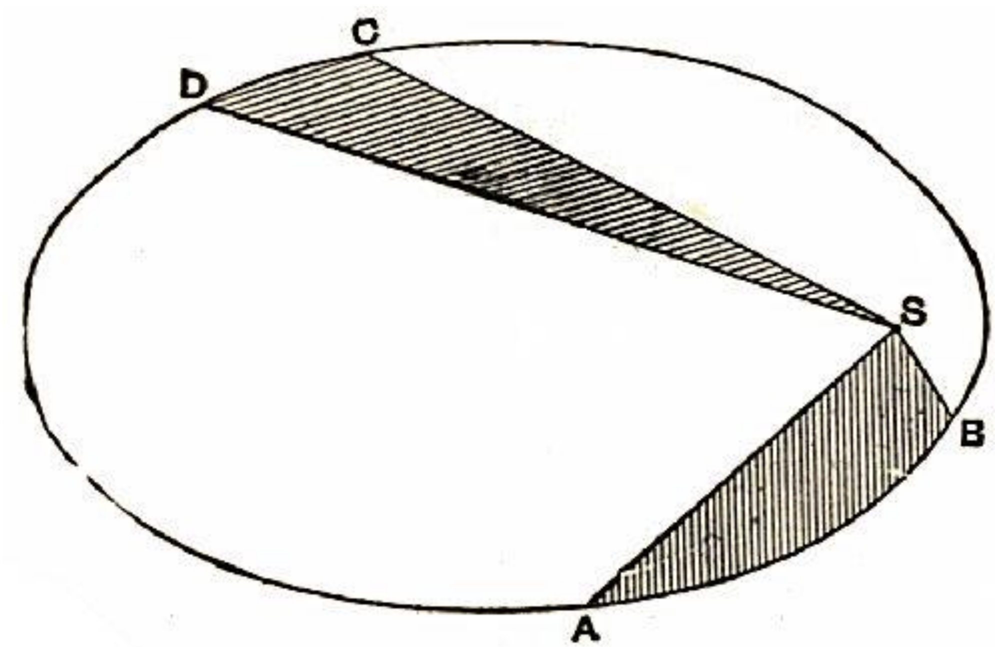

Fig. 39.—Equal Areas in Equal Times.

For example, if the two shaded portions, A B S and D C S, are equal in area, then the times occupied by the planet in travelling over the portions of the ellipse, A B and C D, are equal. If the one area be greater than the other, then the times required are in the proportion of the areas.

This law being admitted, the reason of the increase in the planet's velocity when it approaches the sun is at once apparent. To accomplish a definite area when near the sun, a larger arc is obviously necessary than at other parts of the path. At the opposite extremity, a small arc suffices for a large area, and the velocity is accordingly less.

These two laws completely prescribe the motion of a planet round the sun. The first defines the path which the planet pursues; the second describes how the velocity of the body varies at different points along its path. But Kepler added to these a third law, which enables us to compare the movements[Pg 142] of two different planets revolving round the same sun. Before stating this law, it is necessary to explain exactly what is meant by the *mean* distance of a planet. In its elliptic path the distance from the sun to the planet is constantly changing; but it is nevertheless easy to attach a distinct meaning to that distance which is an average of all the distances. This average is called the mean distance. The simplest way of finding the mean distance is to add the greatest of these quantities to the least, and take half the sum. We have already defined the periodic time of the planet; it is the number of days which the planet requires for the completion of a journey round its path. Kepler's third law establishes a relation between the mean distances and the periodic times of the various planets. That relation is stated in the following words:—

"*The squares of the periodic times are proportional to the cubes of the mean distances*."

Kepler knew that the different planets had different periodic times; he also saw that the greater the mean distance of the planet the greater was its periodic time, and he was determined to find out the connection between the two. It was easily found that it would not be true to say that the periodic time is merely proportional to the mean distance. Were this the case, then if one planet had a distance twice as great as another, the periodic time of the former would have been double that of the latter; observation showed, however, that the periodic time of the more distant planet exceeded twice, and was indeed nearly three times, that of the other. By repeated trials, which would have exhausted the patience of one less confident in his own sagacity, and less assured of the accuracy of the observations which he sought to interpret, Kepler at length discovered the true law, and expressed it in the form we have stated.

To illustrate the nature of this law, we shall take for comparison the earth and the planet Venus. If we denote the mean distance of the earth from the sun by unity then the mean distance of Venus from the sun is 0·7233. Omitting decimals beyond the first place, we can represent the periodic[Pg 143] time of the earth as 365·3 days, and the periodic time of Venus as 224·7 days. Now the law which Kepler asserts is that the square of 365·3 is to the square of 224·7 in the same proportion as unity is to the cube of 0·7233. The reader can easily verify the truth of this identity by actual multiplication. It is, however, to be remembered that, as only four figures have been retained in the expressions of the periodic times, so only four figures are to be considered significant in making the calculations.

The most striking manner of making the verification will be to regard the time of the revolution of Venus as an unknown quantity, and deduce it from the known revolution of the earth and the mean distance of Venus. In this way, by assuming Kepler's law, we deduce the cube of the periodic time by a simple proportion, and the resulting value of 224·7 days can then be obtained. As a matter of fact, in the calculations of astronomy, the distances of the planets are usually ascertained from Kepler's law. The periodic time of the planet is an element which can be measured with great accuracy; and once it is known, then the square of the mean distance, and consequently the mean distance itself, is determined.

Such are the three celebrated laws of Planetary Motion, which have always been associated with the name of their discoverer. The profound skill by which these laws were elicited from the mass of observations, the intrinsic beauty of the laws themselves, their widespread generality, and the bond of union which they have established between the various members of the solar system, have given them quite an exceptional position in astronomy.

As established by Kepler, these planetary laws were merely the results of observation. It was found, as a matter of fact, that the planets did move in ellipses, but Kepler assigned no reason why they should adopt this curve rather than any other. Still less was he able to offer a reason why these bodies should sweep over equal areas in equal times, or why that third law was invariably obeyed. The laws as they came from Kepler's hands stood out as three[Pg 144] independent truths; thoroughly established, no doubt, but unsupported by any arguments as to why these movements rather than any others should be appropriate for the revolutions of the planets.

It was the crowning triumph of the great law of universal gravitation to remove this empirical character from Kepler's laws. Newton's grand discovery bound together the three isolated laws of Kepler into one beautiful doctrine. He showed not only that those laws are true, but he showed why they must be true, and why no other laws could have been true. He proved to demonstration in his immortal work, the "Principia," that the explanation of the famous planetary laws was to be sought in the attraction of gravitation. Newton set forth that a power of attraction resided in the sun, and as a necessary consequence of that attraction every planet must revolve in an elliptic orbit round the sun, having the sun as one focus; the radius of the planet's orbit must sweep over equal areas in equal times; and in comparing the movements of two planets, it was necessary to have the squares of the periodic times proportional to the cubes of the mean distances.

As this is not a mathematical treatise, it will be impossible for us to discuss the proofs which Newton has given, and which have commanded the immediate and universal acquiescence of all who have taken the trouble to understand them. We must here confine ourselves only to a very brief and general survey of the subject, which will indicate the character of the reasoning employed, without introducing details of a technical character.

Let us, in the first place, endeavour to think of a globe freely poised in space, and completely isolated from the influence of every other body in the universe. Let us imagine that this globe is set in motion by some impulse which starts it forward on a rapid voyage through the realms of space. When the impulse ceases the globe is in motion, and continues to move onwards. But what will be the path which it pursues? We are so accustomed to see a stone thrown into the air moving in a curved path, that we might[Pg 145] naturally think a body projected into free space will also move in a curve. A little consideration will, however, show that the cases are very different. In the realms of free space we find no conception of upwards or downwards; all paths are alike; there is no reason why the body should swerve to the right or to the left; and hence we are led to surmise that in these circumstances a body, once started and freed from all interference, would move in a straight line. It is true that this statement is one which can never be submitted to the test of direct experiment. Circumstanced as we are on the surface of the earth, we have no means of isolating a body from external forces. The resistance of the air, as well as friction in various other forms, no less than the gravitation towards the earth itself, interfere with our experiments. A stone thrown along a sheet of ice will be exposed to but little resistance, and in this case we see that the stone will take a straight course along the frozen surface. A stone similarly cast into empty space would pursue a course absolutely rectilinear. This we demonstrate, not by any attempts at an experiment which would necessarily be futile, but by indirect reasoning. The truth of this principle can never for a moment be doubted by one who has duly weighed the arguments which have been produced in its behalf.

Admitting, then, the rectilinear path of the body, the next question which arises relates to the velocity with which that movement is performed. The stone gliding over the smooth ice on a frozen lake will, as everyone has observed, travel a long distance before it comes to rest. There is but little friction between the ice and the stone, but still even on ice friction is not altogether absent; and as that friction always tends to stop the motion, the stone will at length be brought to rest. In a voyage through the solitudes of space, a body experiences no friction; there is no tendency for the velocity to be reduced, and consequently we believe that the body could journey on for ever with unabated speed. No doubt such a statement seems at variance with our ordinary experience. A sailing ship makes no progress on the sea when the[Pg 146] wind dies away. A train will gradually lose its velocity when the steam has been turned off. A humming-top will slowly expend its rotation and come to rest. From such instances it might be plausibly argued that when the force has ceased to act, the motion that the force generated gradually wanes, and ultimately vanishes. But in all these cases it will be found, on reflection, that the decline of the motion is to be attributed to the action of resisting forces. The sailing ship is retarded by the rubbing of the water on its sides; the train is checked by the friction of the wheels, and by the fact that it has to force its way through the air; and the atmospheric resistance is mainly the cause of the stopping of the humming-top, for if the air be withdrawn, by making the experiment in a vacuum, the top will continue to spin for a greatly lengthened period. We are thus led to admit that a body, once projected freely in space and acted upon by no external resistance, will continue to move on for ever in a straight line, and will preserve unabated to the end of time the velocity with which it originally started. This principle is known as the *first law of motion*.

Let us apply this principle to the important question of the movement of the planets. Take, for instance, the case of our earth, and let us discuss the consequences of the first law of motion. We know that the earth is moving each moment with a velocity of about eighteen miles a second, and the first law of motion assures us that if this globe were submitted to no external force, it would for ever pursue a straight track through the universe, nor would it depart from the precise velocity which it possesses at the present moment. But is the earth moving in this manner? Obviously not. We have already found that our globe is moving round the sun, and the comprehensive laws of Kepler have given to that motion the most perfect distinctness and precision. The consequence is irresistible. The earth cannot be free from external force. Some potent influence on our globe must be in ceaseless action. That influence, whatever it may be, constantly deflects the earth from the rectilinear path which it tends to pursue, and constrains it to trace out an ellipse instead of a straight line.

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The great problem to be solved is now easily stated. There must be some external agent constantly influencing the earth. What is that agent, whence does it proceed, and to what laws is it submitted? Nor is the question confined to the earth. Mercury and Venus, Mars, Jupiter, and Saturn, unmistakably show that, as they are not moving in rectilinear paths, they must be exposed to some force. What is this force which guides the planets in their paths? Before the time of Newton this question might have been asked in vain. It was the splendid genius of Newton which supplied the answer, and thus revolutionised the whole of modern science.

The data from which the question is to be answered must be obtained from observation. We have here no problem which can be solved by mere mathematical meditation. Mathematics is no doubt a useful, indeed, an indispensable, instrument in the enquiry; but we must not attribute to mathematics a potency which it does not possess. In a case of this kind, all that mathematics can do is to interpret the results obtained by observation. The data from which Newton proceeded were the observed phenomena in the movement of the earth and the other planets. Those facts had found a succinct expression by the aid of Kepler's laws. It was, accordingly, the laws of Kepler which Newton took as the basis of his labours, and it was for the interpretation of Kepler's laws that Newton invoked the aid of that celebrated mathematical reasoning which he created.

The question is then to be approached in this way: A planet being subject to *some* external influence, we have to determine what that influence is, from our knowledge that the path of each planet is an ellipse, and that each planet sweeps round the sun over equal areas in equal times. The influence on each planet is what a mathematician would call a force, and a force must have a line of direction. The most simple conception of a force is that of a pull communicated along a rope, and the direction of the rope is in this case the direction of the force. Let us imagine that the force exerted on each planet is imparted by an invisible rope. Kepler's[Pg 148] laws will inform us with regard to the direction of this rope and the intensity of the strain transmitted through it.

The mathematical analysis of Kepler's laws would be beyond the scope of this volume. We must, therefore, confine ourselves to the results to which they lead, and omit the details of the reasoning. Newton first took the law which asserted that the planet moved over equal areas in equal times, and he showed by unimpeachable logic that this at once gave the direction in which the force acted on the planet. He showed that the imaginary rope by which the planet is controlled must be invariably directed towards the sun. In other words, the force exerted on each planet was at all times pointed from the planet towards the sun.

It still remained to explain the intensity of the force, and to show how the intensity of that force varied when the planet was at different points of its path. Kepler's first law enables this question to be answered. If the planet's path be elliptic, and if the force be always directed towards the sun at one focus of that ellipse, then mathematical analysis obliges us to say that the intensity of the force must vary inversely as the square of the distance from the planet to the sun.

The movements of the planets, in conformity with Kepler's laws, would thus be accounted for even in their minutest details, if we admit that an attractive power draws the planet towards the sun, and that the intensity of this attraction varies inversely as the square of the distance. Can we hesitate to say that such an attraction does exist? We have seen how the earth attracts a falling body; we have seen how the earth's attraction extends to the moon, and explains the revolution of the moon around the earth. We have now learned that the movement of the planets round the sun can also be explained as a consequence of this law of attraction. But the evidence in support of the law of universal gravitation is, in truth, much stronger than any we have yet presented. We shall have occasion to dwell on this matter further on. We shall show not only how the sun attracts the planets, but how the planets attract each other; and we shall find how this mutual attraction of the planets has led to remarkable discoveries,[Pg 149] which have elevated the law of gravitation beyond the possibility of doubt.

Admitting the existence of this law, we can show that the planets must revolve around the sun in elliptic paths with the sun in the common focus. We can show that they must sweep over equal areas in equal times. We can prove that the squares of the periodic times must be proportional to the cubes of their mean distances. Still further, we can show how the mysterious movements of comets can be accounted for. By the same great law we can explain the revolutions of the satellites. We can account for the tides, and for other phenomena throughout the Solar System. Finally, we shall show that when we extend our view beyond the limits of our Solar System to the beautiful starry systems scattered through space, we find even there evidence of the great law of universal gravitation.

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CHAPTER VI.

THE PLANET OF ROMANCE.

Outline of the Subject—Is Mercury the Planet nearest the Sun?—Transit of an Interior Planet across the Sun—Has a Transit of Vulcan ever been seen?—Visibility of Planets during a Total Eclipse of the Sun—Professor Watson's Researches in 1878.

Provided with a general survey of the Solar System, and with such an outline of the law of universal gravitation as the last chapter has afforded us, we commence the more detailed examination of the planets and their satellites. We shall begin with the planets nearest to the sun, and then we shall gradually proceed outwards to one planet after another, until we reach the confines of the system. We shall find much to occupy our attention. Each planet is itself a globe, and it will be for us to describe as much as is known of it. The satellites by which so many of the planets are accompanied possess many points of interest. The circumstances of their discovery, their sizes, their movements, and their distances must be duly considered. It will also be found that the movements of the planets present much matter for reflection and examination. We shall have occasion to show how the planets mutually disturb each other, and what remarkable consequences have arisen from these influences. We must also occasionally refer to the important problems of celestial measuring and celestial weighing. We must show how the sizes, the weights, and the distances of the various members of our system are to be discovered. The greater part of our task will fortunately lead us over ground which is thoroughly certain, and where the results have been confirmed by frequent observation. It happens, however, that at the very outset of[Pg 151] our course we are obliged to deal with observations which are far from certain. The existence of a planet much closer to the sun than those hitherto known has been asserted by competent authority. The question is still unsettled, but the planet cannot at present be found. Hence it is that we have called the subject of this chapter, The Planet of Romance.

It had often been thought that Mercury, long supposed to be the nearest planet to the sun, was perhaps not really the body entitled to that distinction. Mercury revolves round the sun at an average distance of about 36,000,000 miles. In the interval between it and the sun there might have been one or many other planets. There might have been one revolving at ten million miles, another at fifteen, and so on. But did such planets exist? Did even one planet revolve inside the orbit of Mercury? There were certain reasons for believing in such a planet. In the movements of Mercury indications were perceptible of an influence that it was at one time thought might have been accounted for by the supposition of an interior planet.[13] But there was necessarily a great difficulty about seeing this object. It must always be close to the sun, and even in the best telescope it is generally impossible to see a star-like point in that position. Nor could such a planet be seen after sunset, for under the most favourable conditions it would set almost immediately after the sun, and a like difficulty would make it invisible at sunrise.

Our ordinary means of observing a planet have therefore completely failed. We are compelled to resort to extraordinary methods if we would seek to settle the great question as to the existence of the intra-Mercurial planets. There are at least two lines of observation which might be expected to answer our purpose.

An opportunity for the first would arise when it happened that the unknown planet came directly between the earth and the sun. In the diagram (Fig. 40) we show the sun at the centre; the internal dotted circle denotes the orbit of the unknown planet, which has received the name of Vulcan before even its very existence has been at all satisfactorily established. The outer circle denotes the orbit of the earth. As Vulcan moves more rapidly than the earth, it will frequently happen that the planet will overtake the earth, so that the three bodies will have the positions represented in the diagram. It would not, however, necessarily follow that Vulcan was exactly between the earth and the luminary. The path of the planet may be tilted, so that, as seen from the earth, Vulcan would be over or under the sun, according to circumstances.

If, however, Vulcan really does exist, we might expect that sometimes the three bodies will be directly in line, and this would then give the desired opportunity of making the telescopic discovery of the planet. We should expect on such an occasion to observe the planet as a dark spot, moving slowly across the face of the sun. The two other planets interior to the earth, namely, Mercury and Venus, are occasionally seen in the act of transit; and there cannot be a doubt that if Vulcan exists, its transits across the sun must be more numerous than those of Mercury, and far more numerous than those of Venus. On the other hand, it may reasonably be anticipated that Vulcan is a small globe, and as it will be much more distant from us than Mercury at the time of its transit, we could not expect that the transit of the planet of romance would be at all comparable as a spectacle with those of either of the two other bodies we have named.

The question arises as to whether telescopic research has ever disclosed anything which can be regarded as a transit of Vulcan. On this point it is not possible to speak with any certainty. It has, on more than one occasion, been asserted by observers that a spot has been seen traversing the sun, and from its shape and general appearance they have presumed it to have been an intra-Mercurial planet. But a close examination of the circumstances in which such observations[Pg 153] have been made has not tended to increase confidence in this presumption. Such discoveries have usually been made by persons little familiar with telescopic observations. It is certainly a significant fact that, notwithstanding the diligent scrutiny to which the sun has been subjected during the past century by astronomers who have specially devoted themselves to this branch of research, no telescopic discovery of Vulcan on the sun has been announced by any really experienced astronomer. The last announcement of a planet having crossed the sun dates from 1876, and was made by a German amateur, but what he thought to have been a planet was promptly shown to have been a small sun-spot, which had been photographed at Greenwich in the course of the daily routine work, and had also been observed at Madrid. From an examination of the whole subject, we are inclined to believe that there is not at this moment any reliable telescopic evidence of the transit of an intra-Mercurial planet over the face of the central luminary.

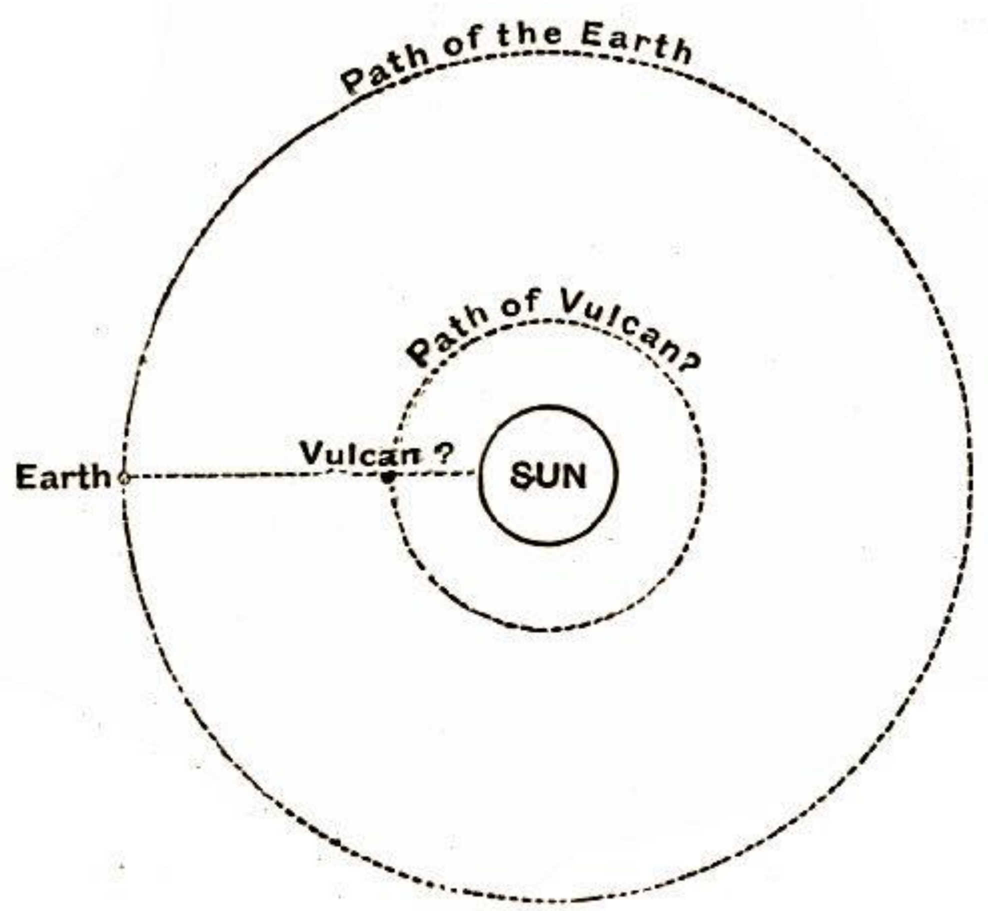

Fig. 40.—

The Transit of the Planet of Romance.

But there is still another method by which we might reasonably hope to detect new planets in the vicinity of the sun. This method is, however, but seldom available. It is only possible when the sun is totally eclipsed.

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When the moon is interposed directly between the earth and the sun, the brightness of day is temporarily exchanged for the gloom of night. If the sky be free from clouds the stars spring forth, and can be seen around the obscured sun. Even if a planet were quite close to the luminary it would be visible on such an occasion if its magnitude were comparable with that of Mercury. Careful preparation is necessary when it is proposed to make a trial of this kind. The danger to be specially avoided is that of confounding the planet with the ordinary stars, which it will probably resemble. The late distinguished American astronomer, Professor Watson, specially prepared to devote himself to this research during the notable total eclipse in 1878. When the eclipse occurred the light of the sun vanished and the stars burst forth. Among them Professor Watson saw an object which to him seemed to be the long-sought intra-Mercurial planet. We should add that this zealous observer saw another object which he at first took to be the star known as Zeta in the constellation Cancer. When he afterwards found that the recorded place of this object did not agree so well as he expected with the known position of this star, he came to the conclusion that it could not be Zeta but must be some other unknown planet. The relative positions of the two objects which he took to be planets agree, however, sufficiently well, considering the difficulties of the observation, with the relative positions of the stars Theta and Zeta Cancri, and it can now hardly be doubted that Watson merely saw these two stars. He maintained, however, that he had noticed Theta Cancri as well as the two planets, but without recording its position. There is, however, a third star, known as 20 Cancri, near the same place, and this Watson probably mistook for Theta. It is necessary to record that Vulcan has not been observed, though specially looked for, during the eclipses which have occurred since 1878, and it is accordingly the general belief among astronomers that no planet has yet been detected within the orbit of Mercury.

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CHAPTER VII.

MERCURY.

The Ancient Astronomical Discoveries—How Mercury was first found—Not easily seen—Mercury was known from the earliest ages—Skill necessary in the Discovery—

The Distinction of Mercury from a Star—Mercury in the East and in the West—The Prediction—How to Observe Mercury—Its Telescopic Appearance—Difficulty of Observing its Appearance—Orbit of Mercury—Velocity of the Planet—Can there be Life on the Planet?—Changes in its Temperature—Transit of Mercury over the Sun—Gassendi's Observations—Rotation of Mercury—The Weight of Mercury.

Long and glorious is the record of astronomical discovery. The discoveries of modern days have succeeded each other with such rapidity, they have so often dazzled our imaginations with their brilliancy, that we are sometimes apt to think that astronomical discovery is a purely modern product. But no idea could be more fundamentally wrong. While we appreciate to the utmost the achievements of modern times, let us endeavour to do justice to the labours of the astronomers of antiquity.

And when we speak of the astronomers of antiquity, let us understand clearly what is meant. The science is now growing so rapidly that each century witnesses a surprising advance; each generation, each decade, each year, has its own rewards for those diligent astronomers by whom the heavens are so carefully scanned. We must, however, project our glance to a remote epoch in time past, if we would view the memorable discovery of Mercury. Compared with it, the discoveries of Newton are to be regarded as very modern achievements; even the announcement of the Copernican system of the heavens is itself a recent event in comparison with the detection of this planet now to be discussed.

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By whom was this great discovery made? Let us see if the question can be answered by the examination of astronomical records. At the close of his memorable life Copernicus was heard to express his sincere regret that he never enjoyed an opportunity of beholding the planet Mercury. He had specially longed to see this body, the movements of which were to such a marked extent illustrative of the theory of the celestial motions which it was his immortal glory to have established, but he had never been successful. Mercury is not generally to be seen so easily as are some of the other planets, and it may well have been that the vapours from the immense lagoon at the mouth of the Vistula obscured the horizon at Frauenburg, where Copernicus dwelt, and thus his opportunities of viewing Mercury were probably even rarer than they are at other places.

The existence of Mercury was certainly quite a familiar fact in the time of Copernicus, and therefore we must look to some earlier epoch for its discovery. In the scanty astronomical literature of the Middle Ages we find occasional references to the existence of this object. We can trace observations of Mercury through remote centuries to the commencement of our era. Records from dates still earlier are not wanting, until at length we come on an observation which has descended to us for more than 2,000 years, having been made in the year 265 before the Christian era. It is not pretended, however, that this observation records the *discovery* of the planet. Earlier still we find the chief of the astronomers at Nineveh alluding to Mercury in a report which he made to Assurbanipal, the King of Assyria. It does not appear in the least degree likely that the discovery was even then a recent one. It may have been that the planet was independently discovered in two or more localities, but all records of such discoveries are totally wanting; and we are ignorant alike of the names of the discoverers, of the nations to which they belonged, and of the epochs at which they lived.

Although this discovery is of such vast antiquity, although it was made before correct notions were entertained as to the[Pg 157] true system of the universe, and, it is needless to add, long before the invention of the telescope, yet it must not be assumed that the detection of Mercury was by any means a simple or obvious matter. This will be manifest when we try to conceive the manner in which the discovery must probably have been made.

Some primæval astronomer, long familiar with the heavens, had learned to recognise the various stars and constellations. Experience had impressed upon him the permanence of these objects; he had seen that Sirius invariably appeared at the same seasons of the year, and he had noticed how it was placed with regard to Orion and the other neighbouring constellations. In the same manner each of the other bright stars was to him a familiar object always to be found in a particular region of the heavens. He saw how the stars rose and set in such a way, that though each star appeared to move, yet the relative positions of the stars were incapable of alteration. No doubt this ancient astronomer was acquainted with Venus; he knew the evening star; he knew the morning star; and he may have concluded that Venus was a body which oscillated from one side of the sun to the other.

We can easily imagine how the discovery of Mercury was made in the clear skies over an Eastern desert. The sun has set, the brief twilight has almost ceased, when lo, near that part of the horizon where the glow of the setting sun still illuminates the sky, a bright star is seen. The primæval astronomer knows that there is no bright star at this place in the heavens. If the object of his attention be not a star, what, then, can it be? Eager to examine this question, the heavens are watched next night, and there again, higher above the horizon, and more brilliant still, is the object seen the night before. Each successive night the body gains more and more lustre, until at length it becomes a conspicuous gem. Perhaps it will rise still higher and higher; perhaps it will increase till it attains the brilliancy of Venus itself. Such were the surmises not improbably made by those who first watched this object; but they were not realised. After a few nights of exceptional splendour the lustre of this[Pg 158] mysterious orb declines. The planet again draws near the horizon at sunset, until at length it sets so soon after the sun that it has become invisible. Is it lost for ever? Years may elapse before another opportunity of observing the object after sunset may be available; but then again it will be seen to run through the same series of changes, though, perhaps, under very different circumstances. The greatest height above the horizon and the greatest brightness both vary considerably.

Long and careful observations must have been made before the primæval astronomer could assure himself that the various appearances might all be attributed to a single body. In the Eastern deserts the phenomena of sunrise must have been nearly as familiar as those of sunset, and in the clear skies, at the point where the sunbeams were commencing to dawn above the horizon, a bright star-like point might sometimes be perceived. Each successive day this object rose higher and higher above the horizon before the moment of sunrise, and its lustre increased with the distance; then again it would draw in towards the sun, and return for many months to invisibility. Such were the data which were presented to the mind of the primitive astronomer. One body was seen after sunset, another body was seen before sunrise. To us it may seem an obvious inference from the observed facts that the two bodies were identical. The inference is a correct one, but it is in no sense an obvious one. Long and patient observation established the remarkable law that one of these bodies was never seen until the other had disappeared. Hence it was inferred that the phenomena, both at sunrise and at sunset, were due to the same body, which oscillated to and fro about the sun.

We can easily imagine that the announcement of the identity of these two objects was one which would have to be carefully tested before it could be accepted. How are the tests to be applied in a case of this kind? There can hardly be a doubt that the most complete and convincing demonstration of scientific truth is found in the fulfilment of prediction. When Mercury had been observed for years, a certain regularity in the recurrence of its visibility was noticed. Once a periodicity[Pg 159] had been fully established, prediction became possible. The time when Mercury would be seen after sunset, the time when it would be seen before sunrise, could be foretold with accuracy! When it was found that these predictions were obeyed to the letter—that the planet was always seen when looked for in accordance with the predictions—it was impossible to refuse assent to the hypothesis on which these predictions were based. Underlying that hypothesis was the assumption that all the various appearances arose from the oscillations of a single body, and hence the discovery of Mercury was established on a basis as firm as the discovery of Jupiter or of Venus.

In the latitudes of the British Islands it is generally possible to see Mercury some time during the course of the year. It is not practicable to lay down, within reasonable limits, any general rule for finding the dates at which the search should be made; but the student who is determined to see the planet will generally succeed with a little patience. He must first consult an almanac which gives the positions of the body, and select an occasion when Mercury is stated to be an evening or a morning star. Such an occasion during the spring months is especially suitable, as the elevation of Mercury above the horizon is usually greater then than at other seasons; and in the evening twilight, about three-quarters of an hour after sunset, a view of this shy but beautiful object will reward the observer's attention.

To those astronomers who are provided with equatorial telescopes such instructions are unnecessary. To enjoy a telescopic view of Mercury, we first turn to the Nautical Almanac, and find the position in which the planet lies. If it happen to be above the horizon, we can at once direct the telescope to the place, and even in broad daylight the planet will very often be seen. The telescopic appearance of Mercury is, however, disappointing. Though it is much larger than the moon, yet it is sufficiently far off to seem insignificant. There is, however, one feature in a view of this planet which would immediately attract attention. Mercury is not usually observed to be a circular object, but more or less crescent-shaped,[Pg 160] like a miniature moon. The phases of the planet are also to be accounted for on exactly the same principles as the phases of the moon. Mercury is a globe composed, like our earth, of materials possessing in themselves no source of illumination. One hemisphere of the planet must necessarily be turned towards the sun, and this side is accordingly lighted up brilliantly by the solar rays. When we look at Mercury we see nothing of the non-illuminated side, and the crescent is due to the foreshortened view which we obtain of the illuminated part. The planet is such a small object that, in the glitter of the naked-eye view, the *shape* of the luminous body cannot be defined. Indeed, even in the much larger crescent of Venus, the aid of the telescope has to be invoked before the characteristic form can be observed. Beyond, however, the fact that Mercury is a crescent, and that it undergoes varying phases in correspondence with the changes in its relative position to the earth and the sun, we cannot see much of the planet. It is too small and too bright to admit of easy delineation of details on its surface. No doubt attempts have been made, and observations have been recorded, as to certain very faint and indistinct markings on the planet, but such statements must be received with great hesitation.

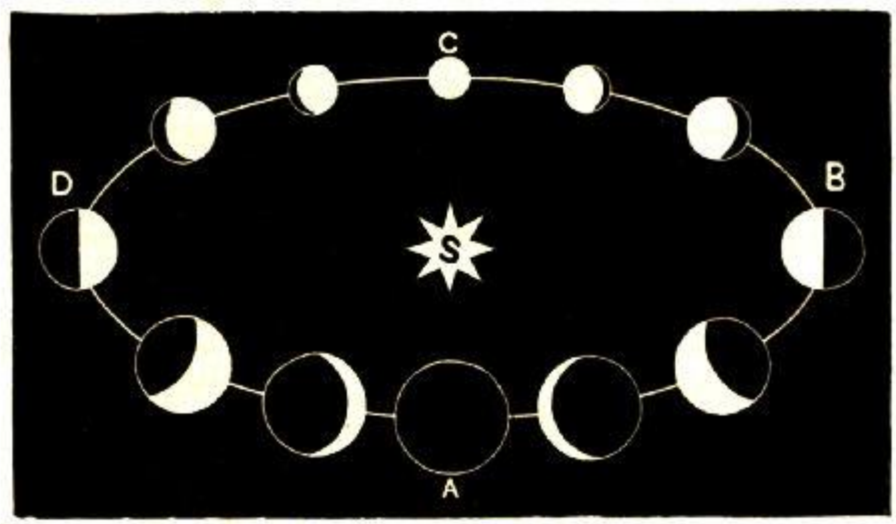

Fig. 41.—The Movement of Mercury, showing the Variations in Phase and in apparent size.

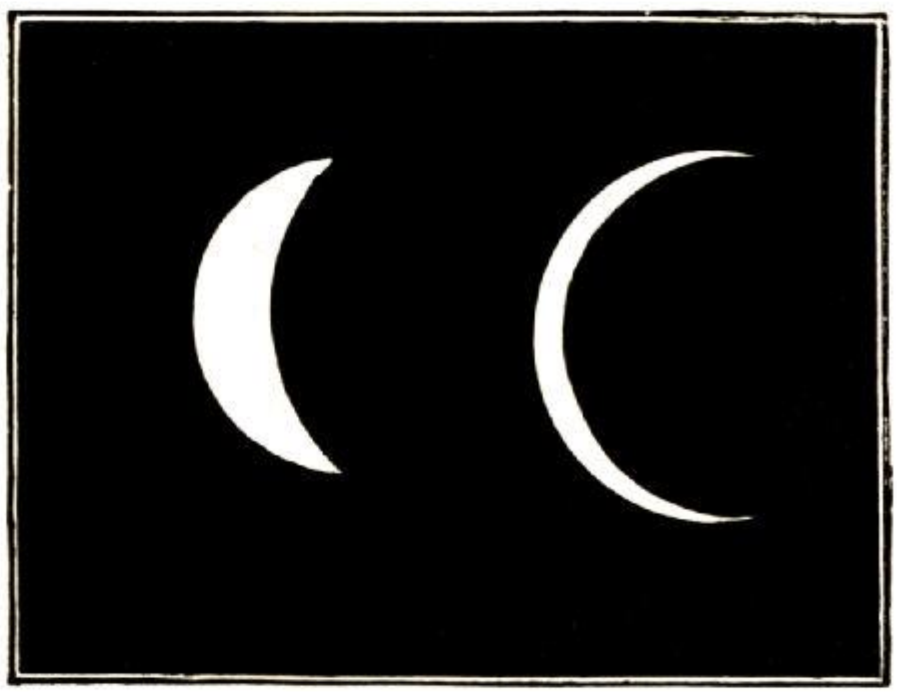
Fig. 42.—Mercury as a Crescent.

The facts which have been thoroughly established with regard to Mercury are mainly numerical statements as to the path it describes around the sun. The time taken by the planet to complete one of its revolutions is eighty-eight days nearly. The average distance from the sun is about 36,000,000 miles, and the mean velocity with which the body moves is over twenty-nine miles a second. We have already alluded to the most characteristic and remarkable feature of the orbit of Mercury. That orbit differs from the paths of all the other large planets by its much greater departure from the circular form. In the majority of cases the planetary orbits are so little elliptic that a diagram of the orbit drawn accurately to scale would not be perceived to differ from a circle unless careful measurements were made. In the case of Mercury the circumstances are different. The elliptic form of the path would be quite unmistakable by the most casual observer. The distance from the sun to the planet fluctuates between very considerable limits. The lowest value it can attain is about 30,000,000 miles; the highest value is about 43,000,000 miles. In accordance with Kepler's second law, the velocity of the planet must exhibit corresponding changes. It must sweep rapidly around that part of his path near the sun, and more slowly round the remote parts of his path. The greatest[Pg 162] velocity is about thirty-five miles a second, and the least is twenty-three miles a second.

For an adequate conception of the movements of Mercury we ought not to dissociate the velocity from the true dimensions of the body by which it is performed. No doubt a speed of twenty-nine miles a second is enormous when compared with the velocities with which daily life makes us familiar. The speed of the planet is not less than a hundred times as great as the velocity of the rifle bullet. But when we compare the sizes of the bodies with their velocities, the velocity of Mercury seems relatively much less than that of the bullet. A rifle bullet traverses a distance equal to its own diameter many thousands of times in a second. But even though Mercury is moving so much faster, yet the dimensions of the planet are so considerable that a period of two minutes will be required for it to move through a distance equal to its diameter. Viewing the globe of the planet as a whole, the velocity of its movement is but a stately and dignified progress appropriate to its dimensions.

As we can learn little or nothing of the true surface of Mercury, it is utterly impossible for us to say whether life can exist on the surface of that planet. We may, however, reasonably conclude that there cannot be life on Mercury in any respect analogous to the life which we know on the earth. The heat of the sun and the light of the sun beat down on Mercury with an intensity many times greater than that which we experience. When this planet is at its utmost distance from the sun the intensity of solar radiation is even then more than four times greater than the greatest heat which ever reaches the earth. But when Mercury, in the course of its remarkable changes of distance, draws in to the warmest part of its orbit, it is exposed to a terrific scorching. The intensity of the sun's heat must then be not less than nine times as great as the greatest radiation to which we are exposed.

These tremendous climatic changes succeed each other much more rapidly than do the variations of our seasons. On Mercury the interval between midsummer and midwinter[Pg 163] is only forty-four days, while the whole year is only eighty-eight days. Such rapid variations in solar heat must in themselves exercise a profound effect on the habitability of Mercury. Mr. Ledger well remarks, in his interesting work,[14] that if there be inhabitants on Mercury the notions of "perihelion" and "aphelion," which are here often regarded as expressing ideas of an intricate or recondite character, must on the surface of that planet be familiar to everybody. The words imply "near the sun," and "away from the sun;" but we do not associate these expressions with any obvious phenomena, because the changes in the distance of the earth from the sun are inconsiderable. But on Mercury, where in six weeks the sun rises to more than double his apparent size, and gives more than double the quantity of light and of heat, such changes as are signified by perihelion and aphelion embody ideas obviously and intimately connected with the whole economy of the planet.

It is nevertheless rash to found any inferences as to climate merely upon the proximity or the remoteness of the sun. Climate depends upon other matters besides the sun's distance. The atmosphere surrounding the earth has a profound influence on heat and cold, and if Mercury have an atmosphere—as has often been supposed—its climate may be thereby modified to any necessary extent. It seems, however, hardly possible to suppose that any atmosphere could form an adequate protection for the inhabitants from the violent and rapid fluctuations of solar radiation. All we can say is, that the problem of life in Mercury belongs to the class of unsolved, and perhaps unsolvable, mysteries.

It was in the year 1629 that Kepler made an important announcement as to impending astronomical events. He had been studying profoundly the movements of the planets; and from his study of the past he had ventured to predict the future. Kepler announced that in the year 1631 the planets Venus and Mercury would both make a transit across the sun, and he assigned the dates to be November 7th for Mercury, and December 6th for Venus. This was at the time a very[Pg 164] remarkable prediction. We are so accustomed to turn to our almanacs and learn from them all the astronomical phenomena which are anticipated during the year, that we are apt to forget how in early times this was impossible. It has only been by slow degrees that astronomy has been rendered so perfect as to enable us to foretell, with accuracy, the occurrence of the more delicate phenomena. The prediction of those transits by Kepler, some years before they occurred, was justly regarded at the time as a most remarkable achievement.

The illustrious Gassendi prepared to apply the test of actual observation to the announcements of Kepler. We can now assign the time of the transit accurately to within a few minutes, but in those early attempts equal precision was not practicable.

Gassendi considered it necessary to commence watching for the transit of Mercury two whole days before the time indicated by Kepler, and he had arranged an ingenious plan for making his observations. The light of the sun was admitted into a darkened room through a hole in the shutter, and an image of the sun was formed on a white screen by a lens. This is, indeed, an admirable and a very pleasing way of studying the surface of the sun, and even at the present day, with our best telescopes, one of the methods of viewing our luminary is founded on the same principle.

Gassendi commenced his watch on the 5th of November, and carefully studied the sun's image at every available opportunity. It was not, however, until five hours after the time assigned by Kepler that the transit of Mercury actually commenced. Gassendi's preparations had been made with all the resources which he could command, but these resources seem very imperfect when compared with the appliances of our modern observatories. He was anxious to note the time when the planet appeared, and for this purpose he had stationed an assistant in the room beneath, who was to observe the altitude of the sun at the moment indicated by Gassendi. The signal to the assistant was to be conveyed by a very primitive apparatus. Gassendi was to stamp on the floor when the critical moment had arrived. In spite of the long[Pg 165] delay, which exhausted the patience of the assistant, some valuable observations were obtained, and thus the first passage of a planet across the sun was observed.

The transits of Mercury are not rare phenomena (there have been thirteen of them during the nineteenth century), and they are chiefly of importance on account of the accuracy which their observation infuses into our calculations of the movements of the planet. It has often been hoped that the opportunities afforded by a transit would be available for procuring information as to the physical character of the globe of Mercury, but these hopes have not been realised.

Spectroscopic observations of Mercury are but scanty. They seem to indicate that water vapour is a probable constituent in the atmosphere of Mercury, as it is in our own.

A distinguished Italian astronomer, Professor Schiaparelli, some years ago announced a remarkable discovery with respect to the rotation of the planet Mercury. He found that the planet rotates on its axis in the same period as it revolves around the sun. The practical consequence of the identity between these two periods is that Mercury always turns the same face to the sun. If our earth were to rotate in a similar fashion, then the hemisphere directed to the sun would enjoy eternal day, while the opposite hemisphere would be relegated to perpetual night. According to this discovery, Mercury revolves around the sun in the same way as the moon revolves around the earth. As the velocity with which Mercury travels round the sun is very variable, owing to the highly elliptic shape of its orbit, while the rotation about its axis is performed with uniform speed, it follows that rather more than a hemisphere (about five-eighths of the surface) enjoys more or less the light of the sun in the course of a Mercurial year.

This important discovery of Schiaparelli has lately been confirmed by an American astronomer, Mr. Lowell, of Arizona, U.S.A., who observed the planet under very favourable conditions with a refractor of twenty-four inches aperture. He has detected on the globe of Mercury certain narrow, dark lines, the very slow shifting of which points to a period of rotation[Pg 166] about its axis exactly coincident with the period of revolution round the sun. The same observer shows that the axis of rotation of Mercury is perpendicular to the plane of the orbit. Mr. Lowell has perceived no sign of clouds or obscurations, and indeed no indication of any atmospheric envelope; the surface of Mercury is colourless, "a geography in black and white."

We may assert that, there is a strong *à priori* probability in favour of the reality of Schiaparelli's discovery. Mercury, being one of the planets devoid of a moon, will be solely influenced by the sun in so far as tidal phenomena are concerned. Owing, moreover, to the proximity of Mercury to the sun, the solar tides on that planet possess an especial vehemence. As the tendency of tides is to make Mercury present a constant face to the sun, there need be little hesitation in accepting testimony that tides have wrought exactly the result that we know they were competent to perform.

Here we take leave of the planet Mercury—an interesting and beautiful object, which stimulates our intellectual curiosity, while at the same time it eludes our attempts to make a closer acquaintance. There is, however, one point of attainable knowledge which we must mention in conclusion. It is a difficult, but not by any means an impossible, task to weigh Mercury in the celestial balance, and determine his mass in comparison with the other globes of our system. This is a delicate operation, but it leads us through some of the most interesting paths of astronomical discovery. The weight of the planet, as recently determined by Von Asten, is about one twenty-fourth part of the weight of the earth, but the result is more uncertain than the determinations of the mass of any of the other larger planets.

[Pg 167]

CHAPTER VIII.

VENUS.

Interés por este planeta—La inesperada de su Apariencia—La Estrella de la Tarde—Visibilidad a la luz del día—Solo iluminada por el Sol—Las fases de Venus—Por qué la Media Luna no es visible para El ojo sin ayuda—variaciones en el tamaño aparente del planeta—el Rotación de Venus—Semejanza de Venus con la Tierra—El Tránsito de Venus—Por qué de tan especial interés—La escala del Sol Sistema—Órbitas de la Tierra y de Venus que no están en la misma Plano—Recurrencia de los tránsitos en pares—Aparición de Venus en Tránsito—Tránsitos de 1874 y 1882—Los primeros tránsitos de 1631 y 1639—Las observaciones de Horrocks y Crabtree—El anuncio de Halley—Cómo la Ruta del Planeta se diferencia de Diferente Lugares—Ilustraciones de Parallax—Viaje a Otaheite—El Resultado de Encke—Valor probable de la distancia al Sol—Observaciones en Dunsink del último tránsito de Venus—La cuestión de una atmósfera a Venus—Otras determinaciones de la distancia al Sol—Estadísticas sobre Venus.

Por una razón, podría haber sido no inapropiado empezar Nuestra revisión del sistema planetario según la descripción del planeta Venus. Esta carrocería no es especialmente destacable por su tamaño, porque allí hay otros planetas cientos de veces más grandes. La órbita de Venus no es duda mayor que la de Mercurio, pero es mucho menor que la de los planetas exteriores. Venus ni siquiera cuenta con la espléndida comitiva de menores Asistentes que otorgan tanta dignidad e interés a los poderosos planetas de nuestro sistema. Sin embargo, el hecho sigue siendo que Venus es insuperable entre el anfitrión planetario. No hablamos ahora de cuerpos celestes solo vistos en el telescopio; Nos referimos a la observación ordinaria que detectó Venus era mucho antes de que se inventaran los telescopios.

¿Quién no se ha encantado con la vista de este magnífico objeto? Lo es No se le ve todo el tiempo. Durante meses juntos, la estrella de la tarde es oculto a la mirada mortal. Sus bellezas[Pág. 168] incluso se ven realzados por el capricho y la incertidumbre que acompaña su aparición. No decimos eso hay algún capricho en los movimientos de Venus, tal como lo conocen quienes consulta diligentemente sus almanaques. Los movimientos del hermoso planeta ¿están prescritos con un detalle prosaico, apenas en armonía con el carácter que normalmente se atribuye a la Diosa del Amor. Pero a quienes sí lo hacen no dedicar especial atención a las estrellas, a la inesperada misma de su apariencia es uno de sus mayores encantos. Venus no lo ha sido notado, sin ser pensado, durante muchos meses. Es una claridad maravillosamente clara noche; El sol acaba de ponerse. El amante de la naturaleza se vuelve para admirar a la Atardecer, como todo amante de la naturaleza lo hará. En la gloria dorada del oeste una se ve a la hermosa gema brillar; Es la estrella de la tarde—

el planeta Venus. Unas semanas después se ve otra hermosa puesta de sol, y ahora el Planet ya no es un punto bajo el resplandor occidental; ha subido muy por encima del horizonte, y continúa siendo un objeto brillante mucho después de que Las sombras de la noche han caído. De nuevo, un poco más tarde, y Venus lo ha hecho alcanzó todo su brillo y esplendor. Toda la hueste celestial—incluso Sirius e incluso Júpiter—deben palidecer ante el espléndido brillo de Venus, La reina inigualable del firmamento.

Tras semanas de esplendor, la altura de Venus al atardecer disminuye, y su brillo comienza a decaer gradualmente. Se hunde hasta la invisibilidad, y es olvidado por la gran mayoría de la humanidad; pero la diosa caprichosa solo se ha movido de un lado al otro del cielo. Antes de que salga el sol, La Estrella de la Mañana se verá en el este. Su esplendor poco a poco aumenta hasta rivalizar con la belleza de la estrella vespertina. Y de nuevo, el El planeta se acerca al sol y permanece perdido durante muchos meses, hasta que se repite el mismo ciclo de cambios, tras un intervalo de un año y siete meses.

Cuando Venus está en su punto más brillante, puede verse fácilmente a plena luz del día A simple vista. Este espectáculo impactante proclama en un De manera inconfundible, la supremacía inigualable de este planeta en comparación con con sus planetas compañeros y con las estrellas fijas. De hecho, en ese momento Venus es de cuarenta[pág. 169] hasta sesenta veces más brillante que cualquier estelar objeto en los cielos del norte.

La hermosa estrella vespertina suele ser un objeto tan llamativo que Puede parecer difícil al principio darse cuenta de que el cuerpo no lo es auto-luminoso. Sin embargo, es imposible dudar de que el planeta realmente es solo un globo oscuro, y en ese sentido se parece a nuestra propia tierra. El el brillo del planeta no es mucho mayor que el del La Tierra en un día soleado. El esplendor de Venus surge enteramente de la Luz reflejada del sol, de la manera ya explicada con respeto A la luna.

No podemos distinguir la característica forma de media luna del planeta a simple vista, que solo muestra un punto brillante demasiado pequeño para posee una forma sensata. Esto debe explicarse desde un punto de vista fisiológico. Los artificios ópticos en el ojo forman una imagen del planeta en el La retina, que necesariamente es muy pequeña. Incluso cuando Venus está más cerca de La Tierra tiene el diámetro del planeta en un ángulo no mucho más que un minuto de arco. En la delicada membrana se encuentra una imagen de Venus así se dibujó aproximadamente una sexta milésima parte de pulgada de diámetro. Genial Como puede ser la delicadeza de la retina, no es suficiente para la percepción de la forma en una imagen tan diminuta. La estructura nerviosa, que se ha descrito como la fuente de la visión, formas demasiado gruesas en un lienzo para la recepción de los detalles de esta pequeña imagen. Por lo tanto, es que a simple vista, la brillante Venus aparece simplemente como un punto brillante. La visión ordinaria no puede distinguir qué forma tiene; Y menos aún puede revelar La verdadera belleza de la media luna.

Si el diámetro de Venus fuera varias veces mayor de lo que realmente es; ¿este cuerpo, por ejemplo, era tan grande como Júpiter o alguno de los otros grandes planetas, entonces su creciente podía ser fácilmente discernida por el A simple vista. Es curioso especular sobre qué podría haber sido el la historia de la astronomía si Venus solo hubiera sido tan grande como Júpiter. ¿Eran Todos los que pudieran ver la forma de media luna sin telescopio, entonces han sido una verdad elemental y casi obvia que Venus debe ser un cuerpo oscuro girando alrededor del sol. La analogía[Pág. 170] entre Venus y nuestro la tierra habría sido percibida de inmediato; y la doctrina que quedó ser descubierto por Copérnico en tiempos relativamente modernos podría no hacerlo Improbable que nos hayan sido transmitidos junto con los otros descubrimientos que han venido de las antiguas naciones del Este.

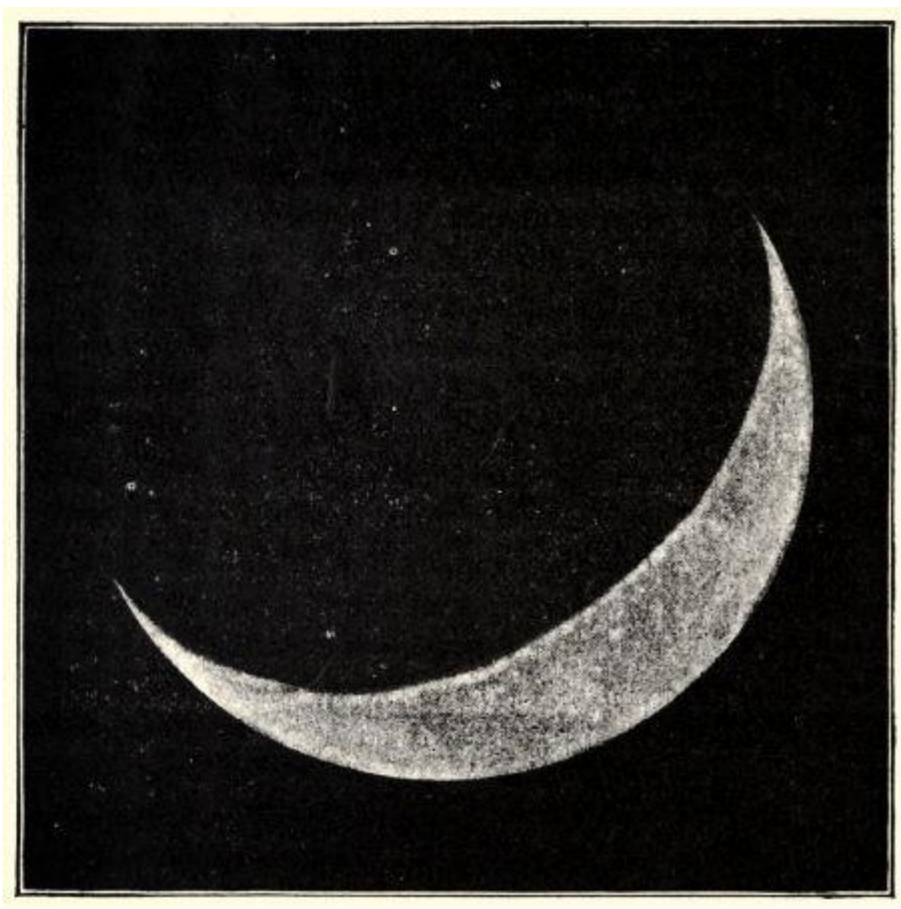
Fig. 43. Venus, 29 de mayo de 1889.

Quizá el dibujo más perfecto de Venus que se haya hecho hasta ahora obtenido es el realizado (Fig. 43) por el profesor E.E. Barnard, el 29 de mayo, 1889, con un ecuatorial de 12 pulgadas, en el Observatorio Lick, que para este y en esta ocasión el profesor Barnard se consideró superior a El de 36 pulgadas. Las marcas mostradas parecen existir indudablemente en el planeta, y en 1897 el profesor Barnard escribe: "Las circunstancias bajo las cuales este dibujo que se hizo es memorable para mí, porque nunca más después condiciones tan perfectas para observar a Venus."

[Pág. 171]

En la Fig. 44 mostramos tres vistas de Venus bajo diferentes aspectos. El El planeta está mucho más cerca de la Tierra cuando se ve la media luna, que parece formar parte de un círculo mucho más grande que el que forma Venus cuando más bien lleno. Este dibujo muestra los diferentes aspectos del globo en sus verdaderas proporciones relativas. Es muy difícil de percibir Claramente cualquier marca en la superficie brillantemente iluminada. A veces los observadores han observado manchas u otras características, y ocasionalmente el las extremidades puntiagudas de los cuernos han sido irregulares, como para demostrar que la superficie de Venus no es lisa. Algunos observadores afirman haber visto manchas blancas en los polos de Venus, en cierto grado más parecidas a las rasgos conspicuos del mismo personaje que se pueden ver en Marte.

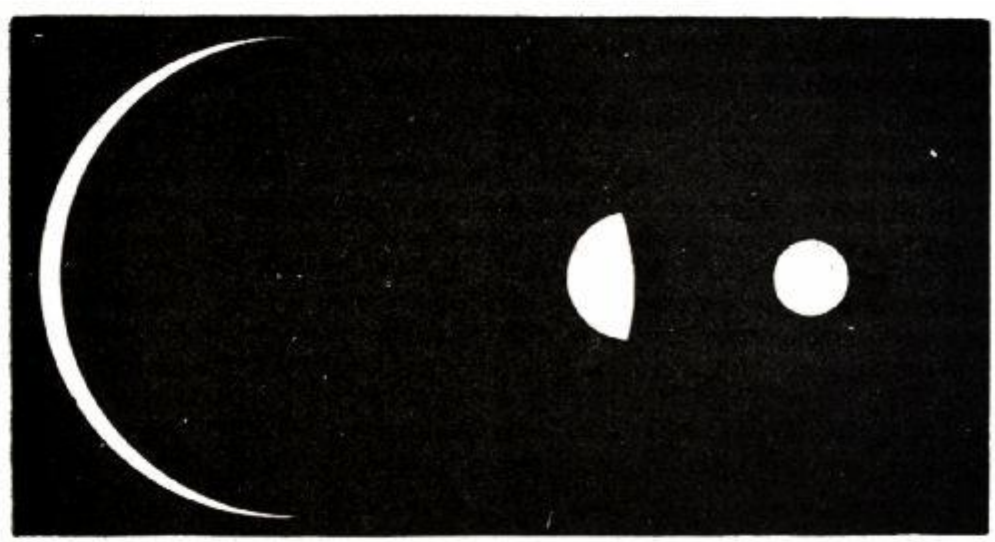
Fig. 44.—Different Aspects of Venus in the Telescope.

Como es tan difícil ver cualquier marca en Venus, apenas estamos pero capaz de dar una respuesta definitiva a la importante cuestión de la Periodo de rotación de este planeta alrededor de su eje. Diversos observadores Durante los últimos doscientos años se han obtenido datos muy insuficientes concluyó que Venus rotó en unas veintitrés horas. Schiaparelli, de Milán, centró su atención en este planeta en 1877 y notó una oscuridad sombra y dos puntos brillantes, todos situados no muy lejos del extremo sur de la media luna. Este astrónomo tan meticuloso observaba[Pág. 172] estos marcaciones durante tres meses, y comprobó que no había cambios perceptible en la posición que ocupaban. Esto era especialmente el caso cuando continuó su guardia durante varias horas consecutivas. Esto el hecho parecía demostrar de forma concluyente que Venus no podía rotar hacia veintitrés horas ni en ningún otro periodo corto. Semana tras semana el las manchas permanecieron inalteradas, hasta que Schiaparelli se convenció de que su Las observaciones solo podían conciliarse con un periodo de rotación entre seis y nueve meses. Naturalmente, concluyó que el periodo era de 225 días—es decir, el periodo que tarda Venus en completar uno revolución alrededor del sol; en otras palabras, Venus siempre gira igual cara al sol.

This remarkable result was confirmed by observations made at Nice; but it has been vigorously assailed by several observers, who maintain that their own drawings can only agree with a period about equal to that of the rotation of our own earth. Schiaparelli's result is, however, well supported by the letters of Mr. Lowell. He has published a number of drawings of Venus made with his 24-inch refractor, and he finds that the rotation is performed in the same time as the planet's orbital revolution, the axis of rotation being perpendicular to the plane of the orbit. The markings seen by Mr. Lowell were long and streaky, and they were always visible whenever his own atmospheric conditions were fairly good.

We have seen that the moon revolves so as to keep the same face always turned towards the earth. We have now seen that the planets Venus and Mercury each appear to revolve in such a way that they keep the same face towards the sun. All these phenomena are of profound interest in the higher departments of astronomical research. They are not mere coincidences. They arise from the operation of the tides, in a manner that will be explained in a later chapter.

It happens that our earth and Venus are very nearly equal in bulk. The difference is hardly perceptible, but the earth has a diameter a few miles greater than that of Venus. There are indications of the existence of an atmosphere around Venus, and the evidence of the spectroscope shows that water vapour is there present.

[Pg 173]

If there be oxygen in the atmosphere of Venus, then it would seem possible that there might be life on that globe not essentially different in character from some forms of life on the earth. No doubt the sun's heat on Venus is greatly in excess of the sun's heat with which we are acquainted, but this is not an insuperable difficulty. We see at present on the earth, life in very hot regions and life in very cold regions. Indeed, with each approach to the Equator we find life more and more exuberant; so that, if water be present on the surface of Venus and if oxygen be a constituent of its atmosphere, we might expect to find in that planet a luxuriant tropical life, of a kind perhaps analogous in some respects to life on the earth.

En nuestro relato sobre el planeta Mercurio, así como en el breve Descripción del hipotético planeta Vulcano, ha sido necesario alusión a los fenómenos presentados por el tránsito de un planeta sobre el Rostro del sol. Un evento así siempre interesa a los astrónomos, y especialmente en el caso de Venus. En los últimos años hemos tenido el oportunidad de presenciar dos de estos raros sucesos. Quizá sí no es demasiado para afirmar que los tránsitos de 1874 y 1882 hayan recibido un grado de atención nunca antes acordado a ninguna astronomía Fenómeno.

El tránsito de Venus no puede describirse como muy llamativo ni hermoso espectáculo. No es ni de lejos tan bonito como un gran cometa o una lluvia de estrellas fugaces. ¿Por qué, entonces, se le considera de tanto? ¿Importancia científica? Es porque el fenómeno nos ayuda a resolver Uno de los mayores problemas que jamás han ocupado la mente del hombre. Por el tránsito de Venus podemos determinar la escala en la que nuestro solar se construye el sistema. De verdad, este es un problema noble. Vamos a detenernos en ello por un momento. En el centro de nuestro sistema tenemos el sol—un majestuoso Globo más de un millón de veces más grande que la Tierra. Ronda circular El sol Tenemos los planetas, de los cuales nuestra Tierra es solo uno. Hay cientos de pequeños planetas. Hay algunos comparables con nuestra Tierra; Hay otros que superan con creces a la Tierra. Además de los planetas allí son otros cuerpos en nuestro sistema.[Pág. 174] Muchos de los planetas van acompañados de sistemas de lunas giratorias. Hay cientos, quizá miles, de cometas. Cada miembro de este estupendo huésped se mueve en una órbita prescrita alrededor del Sol, y en conjunto forman el sistema solar.

Es relativamente fácil aprender las proporciones de este sistema, a miden las distancias relativas de los planetas al sol, e incluso al tamaños relativos de los propios planetas. Las dificultades peculiares son, sin embargo, experimentado cuando buscamos determinar el *tamaño* real de la así como su forma. Es esta última cuestión la que el el tránsito de Venus nos ofrece un método para resolver.

Mira, por ejemplo, un mapa ordinario de Europa. Vemos los distintos países trazados con precisión; podemos contar los cursos de los ríos; podemos decir que Francia es más grande que Inglaterra y Rusia más grande luego Francia; Pero por muy perfectamente construido que esté el mapa, Es necesario algo más antes de que podamos tener una concepción completa de las dimensiones del país. Debemos conocer *la escala en la que el mapa se dibuja*. El mapa contiene una línea de referencia con ciertas marcas. Esta línea sirve para dar la escala del mapa. Su deber es decirnos que una pulgada en el mapa corresponde a tantas millas en la superficie real. A menos que se complemente con la escala, el mapa sería bastante inútil Para muchos propósitos. Supongamos que la consultamos para elegir un ruta de Londres a Viena, podemos ver de inmediato la dirección a ser tomado y las diversas ciudades y países a recorrer; pero a menos que Consulta la pequeña escala en la esquina, el mapa no dirá cuántos El viaje está por durar kilómetros.

Se puede construir fácilmente un mapa del sistema solar. Podemos sacar de ella las órbitas de algunos planetas y de sus satélites, y podemos incluye muchos de los cometas. Podemos asignar a los planetas y a la orbita sus proporciones adecuadas. Pero para hacer que el mapa sea bastante eficiente Hace falta algo más. Debemos tener la escala que nos diga ¿cuántos millones de millas en el cielo corresponden a una pulgada de la Mapa. Es en este punto cuando nos encontramos con una dificultad.[pág. 175] Sin embargo, hay, Varias formas de resolver el problema, aunque todas son difíciles y laborioso. El método más celebrado (aunque lejos de ser el mejor) es que presentado con ocasión del tránsito de Venus. Aquí, entonces, reside el importancia de este raro evento. Es uno de los medios más conocidos de encontrar la escala real sobre la que se construye nuestro sistema. Observa el Toda la importancia del problema. Una vez determinada la escala, entonces todo se sabe. Sabemos el tamaño del sol; conocemos su distancia; Lo sabemos la mayor parte de Júpiter y las distancias a las que giran sus satélites; conocemos las dimensiones de los cometas y el número de millas a las que se corresponde se retiran en sus deambulaciones; sabemos la velocidad del disparo estrellas; Y aprendemos la importante lección de que nuestra Tierra es solo una de ellas Los miembros menores de la familia del Sol.

Como el camino de Venus está dentro del de la tierra, y mientras Venus se mueve Más rápido que la Tierra, se deduce que la Tierra es frecuentemente pasó junto al planeta, y justo en el momento crítico a veces lo hará ocurre que la Tierra, el planeta y el sol están en la misma recta línea. Entonces podemos ver a Venus en la cara del sol, y esta es la fenómeno que llamamos *el tránsito de Venus*. Es, efectivamente, bastante claro que si los tres cuerpos estuvieran exactamente en línea, un observador en La Tierra, al mirar el planeta, lo vería resaltado vívidamente contra el brillante fondo del sol.

Teniendo en cuenta que la Tierra es invadida por Venus una vez cada diecinueve meses, podría parecer que los tránsitos del planeta deberían ocurrir con frecuencia correspondiente. Esto no es así; el tránsito de Venus es un hecho extremadamente raro, y a menudo cien años o más sin que ocurriera ni una sola vez. La rareza de estos fenómenos surge del hecho de que la trayectoria del planeta está inclinada hacia el plano de la órbita terrestre; de modo que durante la mitad de su trayectoria Venus está por encima el plano de la órbita terrestre, y en la otra mitad está por debajo. Cuando Venus supera la Tierra, la línea de la Tierra a Venus lo hará por lo tanto, normalmente pasan por encima o por debajo del sol. Sin embargo, si es que debería[Pág. 176] ocurren que Venus supera la Tierra en o cerca de cualquiera de los puntos de que el plano de la órbita de Venus pasa por la de la Tierra, entonces los tres cuerpos estarán alineados, y un tránsito de Venus será La consecuencia. La rareza de la ocurrencia de un tránsito no necesita Ya no sería un misterio. La tierra pasa por una de las partes críticas cada diciembre, y durante el otro cada junio. Si ocurre que el la conjunción de Venus ocurre el 6 de junio o cerca de, o cerca de, el 6 de junio o el 7 de diciembre, entonces ocurrirá un tránsito de Venus en esa conjunción, pero en ninguna otra circunstancias.

La ley más notable en referencia a la repetición de la fenómeno es el conocido intervalo de ocho años. Los tránsitos pueden ser todos agrupados en pares, los dos tránsitos de cualquier par separados por un intervalo de ocho años. Por ejemplo, un tránsito de Venus tuvo lugar en 1761 y de nuevo en 1769. No se permiten más tránsitos ocurrieron hasta los que se vieron en 1874 y 1882. Entonces, de nuevo, aparece un Intervalo largo, para otro tránsito no ocurrirá hasta 2004, pero será seguida por otra en 2012.

Esta disposición de los tránsitos en pares permite una respuesta muy sencilla Explicación. Sucede que el tiempo periódico de Venus lleva un notable relación con el tiempo periódico de la Tierra. El planeta Realiza trece revoluciones alrededor del sol en casi el mismo tiempo que la Tierra necesita para ocho revoluciones. Si, por tanto, Venus y la Tierra estaba alineada con el sol en 1874, luego en ocho años más bien la tierra volverá a encontrarse en el mismo lugar; y también Venus, pues acaba de lograr trece revoluciones. Un tránsito de que Venus haya ocurrido en la primera ocasión, también debe haber un tránsito ocurren en la segunda.

Sin embargo, no se supone que cada ocho años los planetas retomará la misma posición con suficiente precisión para que intervalo regular de tránsito de ocho años. Solo es aproximadamente cierto que trece revoluciones de Venus coinciden con ocho revoluciones de la tierra. Cada recurrencia de conjunción ocurre en un poco diferente posición de los planetas, de modo que cuando llegaron los dos planetas juntos de nuevo en el año 1890 el punto de conjunción[Pág. 177] hasta ahora separado del punto crítico que la línea de la Tierra a Venus no intersectó con el sol, y por tanto, aunque Venus pasó muy cerca del sol, pero no hubo tránsito.

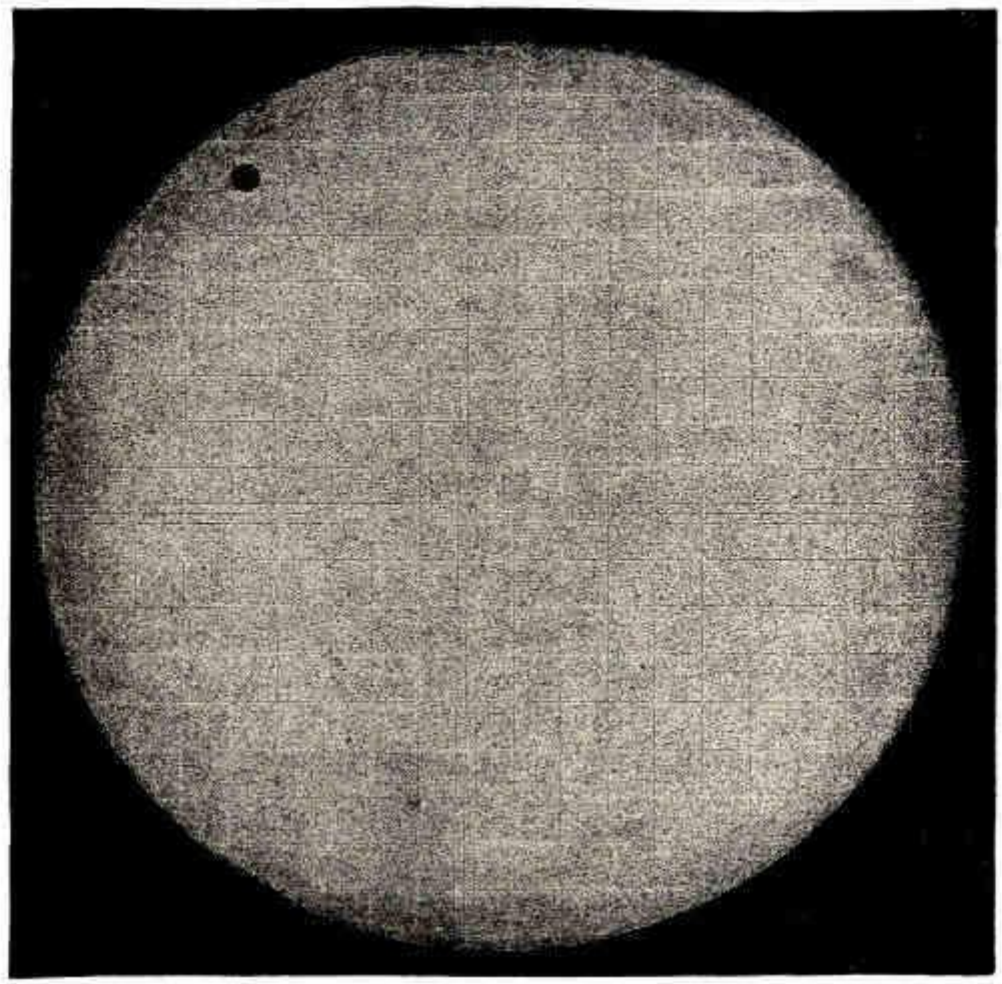

Fig. 45.— Venus en el Sol en el Tránsito de 1874.

La Fig. 45 representa el tránsito de Venus en 1874. Se toma de un fotografía obtenida, durante el suceso, por M. Janssen. Su telescopio se dirigía hacia el sol durante los minutos intensos en que duró, y así se representó una imagen del sol en la fotografía Placas colocadas en el telescopio. El círculo más claro representa el disco de El sol. En ese disco vemos la imagen redonda y nítida[pág. 178] de Venus, mostrando la apariencia característica del planeta durante el avance de la Tránsito. Las únicas otras características que se notan son algunas de las solares manchas, mostradas de forma bastante tenue, y una red de líneas marcadas en un placa de vidrio a lo largo del campo de visión del telescopio para facilitar Medidas.

El boceto adjunto (Fig. 46) muestra el curso del planeta perseguido en su paso por el sol en dos ocasiones en 1874 y 1882. Nuestra generación ha tenido la suerte de presenciar a los dos Ocurrencias indicadas en esta imagen. El círculo blanco indica el disco del sol; el planeta invade la superficie blanca, y al principio es como una mordida en el margen del sol. Poco a poco la mancha negra se va colando delante del sol, hasta que, tras casi media hora, el disco negro está completamente visible. Poco a poco el planeta avanza hacia otro lado, seguido por cientos de telescopios de todas las partes accesibles del globo El fenómeno es visible, hasta que en el largo, en el transcurso de unos pocos horas, emerge al otro lado.

Será útil hacer un breve repaso a los diferentes tránsitos de Venus, de la cual existe ningún registro histórico. No son muchos. Cientos de estos fenómenos han ocurrido desde que el hombre llegó por primera vez a la tierra. No fue hasta la llegada del año 1631 que se llamó la atención comenzó a dirigirse al asunto, a través del tránsito que sin duda ocurrió ese año y nadie se dio cuenta. El éxito de Gassendi al observar el tránsito de Mercurio, al que nos hemos referido en el el capítulo anterior le llevó a esperar que él también tendría la misma suerte en observando el tránsito de Venus, que Kepler también había predicho. Gassendi miré el sol los días 4, 5 y 6 de diciembre. Lo miró de nuevo el día 7, pero no vio rastro del planeta. Ahora sabemos que razón. El tránsito de Venus tuvo lugar durante la noche, entre 6º y 7º, y por tanto debió ser invisible para los europeos observadores.

Kepler no se había dado cuenta de que otro tránsito ocurriría en 1639. Esto El descubrimiento fue realizado por otro astrónomo, y es con el que La historia del tema puede[pág. 179] Que se diga que empieza. Fue la primera ocasión en la que el fenómeno fue realmente presenciado; Ni tampoco luego visto por muchos. Hasta donde se sabe, solo fue presenciado por dos personas.

Fig. 46.—El camino de Venus a través del Sol en la Tránsitos de 1874 y 1882.

Un joven y apasionado astrónomo inglés, llamado Horrocks, había emprendido algunos cálculos sobre los movimientos de Venus. Descubrió que el tránsito de Venus se repetiría en 1639, y él se preparó para Verifica el hecho. El sol salió brillante en la mañana del día—que resultó ser un domingo. La profesión clerical, que Horrocks Después, aquí chocó con sus deseos como astrónomo. Él nos cuenta que a los nueve años fue llamado por un negocio de alto nivel importancia—sin duda refiriéndose a sus deberes oficiales; pero el servicio fue interpretado rápidamente, y poco antes de las diez volvió a estar en el Mira, solo para encontrar el rostro brillante del sol sin nada inusual Feature. Estaba marcada con una mancha, pero nada que pudiera[pág. 180] Que me equivoques para un planeta. De nuevo, al mediodía, se produjo una interrupción; iba a la iglesia, Pero estaba de vuelta por una. Tampoco eran estos los únicos impedimentos para su observaciones. El sol también estuvo más o menos nublado durante parte de el día. Sin embargo, a las tres y cuarto de la tarde, su oficina de oficina El trabajo había terminado; Las nubes se habían disipado, y él volvió a su observaciones. Para su intensa alegría, entonces vio al sol la redonda, mancha oscura, que de inmediato fue identificada como el planeta Venus. El las observaciones no podían durar mucho; era el pleno invierno, y el El sol se estaba poniendo rápidamente. Solo había media hora disponible, pero lo había hecho hizo preparativos tan cuidadosos de antemano que bastó para que pudiera hacerlo para conseguir algunas medidas valiosas.

Horrocks ya había conocido previamente a su amigo, William Crabtree, con el inminente suceso. Por tanto, Crabtree estaba de guardia, y logró ver el tránsito; una imagen impactante de la famosa obra de Crabtree la observación se muestra en uno de los hermosos frescos del Ayuntamiento en Manchester. Pero a nadie más Horrocks le había comunicado el inteligencia; como él dice, "Espero ser excusado por no informar a otros de mis amigos del fenómeno esperado, pero a la mayoría les importa poco para cosas de este tipo, que preferían más a sus halcones y sabuesos No digas nada peor; y aunque Inglaterra no está exenta de partidarios de la astronomía, con algunos de los cuales conozco, no pude comunicarles el agradables noticias, habiéndome dado tan poco tiempo."

No fue hasta mucho tiempo después cuando se comprendió la plena importancia del tránsito de Venus fue apreciado. Casi un siglo había pasado cuando el el gran astrónomo Halley (1656–1742) llamó la atención sobre el tema. El El siguiente tránsito tuvo lugar en 1761, y cuarenta y cinco años antes evento Halley explicó su célebre método para encontrar la distancia de el sol mediante el tránsito de Venus. [15] Entonces tenía sesenta años años de edad; no podía esperar que viviera para presenciar el evento; pero en noble[pág. 181] lenguaje Él recomienda el problema ante la notificación de los eruditos, y así se dirige a la Royal Society de Londres:—"Y esto es lo que ahora deseo presentar ante esta ilustre Sociedad, que preveo que continuará durante mucho tiempo, que pueda explicarlo de antemano a los jóvenes astrónomos, que quizá vivan para observar estas cosas, un método por el cual la inmensa distancia del sol puede ser verdaderamente obtenido.... Por tanto, lo recomiendo una y otra vez a quienes tengan curiosidad astrónomos que, cuando yo muera, tendrán la oportunidad de observar estas cosas, que recordarían esto, mi advertencia, y se esfuerzan con todas sus fuerzas para lograr el observaciones, y les deseo sinceramente éxito imaginable—en la Primero, que no puedan ser por la inusual oscuridad de un nublado el cielo se priva de esta vista tan deseable, y luego que, teniendo determinó con mayor precisión las magnitudes de las órbitas planetarias, puede retribuir a su fama y gloria inmortales." Halley vivió hasta un buen momento de viejo, pero murió diecinueve años antes de que ocurriera el tránsito.

El estudiante de astronomía que desea aprender cómo se realiza el tránsito de Venus Dirá la distancia al sol, debe prepararse para encontrarse con un un problema geométrico de no poca complejidad. No podemos dar a la Sujeta los detalles necesarios para una explicación completa. Todos podemos intentar ofrecer una explicación general del método, suficiente para que el lector vea que el tránsito de Venus realmente lo hace contienen todos los elementos necesarios para la solución del problema.

Primero debemos explicar claramente la concepción que se conoce astrónomos llamados *Parallax*; porque es por paralaje que el distancia del sol, o, de hecho, la distancia de cualquier otro celeste el cuerpo, debe determinarse. Tomemos un ejemplo sencillo. Quédate cerca una ventana desde la que puedas mirar edificios, o los árboles, las nubes, o cualquier objeto lejano. Coloca sobre el cristal una tira fina de papel en posición vertical en medio de uno de los cristales. Cierra el ojo derecho y nota con el ojo izquierdo la posición de la tira de papel respecto a la objetos en el fondo. Luego, mientras siguen en el mismo posición, cierra el ojo izquierdo y[Pág. 182] De nuevo, observe la posición de la Tira de papel con el ojo derecho. Verás que la posición de El papel sobre el fondo ha cambiado. Mientras me siento en mi despacho y miro Por la ventana veo una tira de papel, con mi ojo derecho, delante de una rama en un árbol a un par de cientos de metros; con mi izquierda Ojo El papel ya no está delante de esa rama, se ha movido a una Posición cerca del contorno del árbol. Este aparente desplazamiento del Tira de papel, relativamente al fondo lejano, es lo que se llama Parallax.

Acércate a la ventana y repites la observación, y verás que *el desplazamiento aparente de la tira aumenta*. Aléjate de la ventana, y el desplazamiento disminuye. Muévete al otro lado de la el desplazamiento es mucho menor, aunque probablemente aún visible. Nosotros así ver que el cambio en el lugar aparente de la tira de papel, como Vista con el ojo derecho o el izquierdo, varía en cantidad ya que la cambios de distancia; pero varía en sentido contrario a la distancia, porque a medida que uno se vuelve mayor, el otro disminuye. Podemos así asociar con cada distancia particular un desplazamiento particular correspondiente. De esto será fácil inferir que si tenemos los medios de midiendo la cantidad de desplazamiento, entonces tenemos la media de calculando la distancia desde el observador hasta la ventana.

Es este principio, aplicado a gran escala, el que nos permite Mide las distancias de los cuerpos celestes. Mira, por ejemplo, el el planeta Venus; Sea esta corresponda a la tira de papel, y sea la el sol, en el que se ve Venus en el acto de tránsito, es el fondo. En lugar de los dos ojos del observador, ahora colocamos dos observatorios en regiones lejanas de la Tierra; observamos Venus desde un observatorio, Lo vemos desde el otro; medimos la cantidad del desplazamiento, y a partir de eso calculamos la distancia del planeta. Todo depende, luego, sobre los medios que tenemos para medir el desplazamiento de Venus visto desde las dos emisoras diferentes. Existen varias formas de logrando esto, pero lo más sencillo es lo que originalmente propuesto por Halley.

[Pág. 183]

Desde el observatorio de A Venus parece perseguir la superior de las dos las vías que se muestran en la figura adjunta (Fig. 47). Desde el observatorio de B sigue la vía inferior, y nos corresponde a nosotros medir la distancia entre las dos vías. Esto se puede lograr de varias maneras. Supongamos que el observador en A anota el tiempo que Venus ha ocupado en cruzando el disco, y que se hagan observaciones similares en B. Como el la pista vista desde B es la mayor, debe seguirse que el tiempo observado en B será mayor que en A. Cuando las observaciones de la Comparando diferentes hemisferios, los *tiempos* observados permitirán que las longitudes de las vías a calcular. Al conocerse las longitudes, su se determinan los lugares en el disco circular del sol, y por tanto el se determina la cantidad de desplazamiento de Venus en tránsito. Así es que se mide la distancia de Venus y la escala del sol. se conoce el sistema.

Fig. 47.—Para ilustrar la observación del tránsito de Venus de dos localidades, A y B, en la Tierra.

Los dos transitos que investigan memorablemente Halley[Pág. 184] referido ocurrió en los años 1761 y 1769. Los resultados de la primera no fueron muy exitoso, a pesar de los arduos trabajos de quienes emprendieron Las observaciones. El tránsito de 1769 es de particular interés, no solo para determinar la distancia del sol, pero también porque dio lugar al primero de los célebres viajes del capitán Cook. Lo fue para ver el tránsito de Venus que el capitán Cook fue comisionado para navegar a Otaheite, y allí, el 3 de junio, en un día espléndido en ese Con un clima exquisito, el fenómeno fue cuidadosamente observado y medido por Observadores diferentes. Simultáneamente con estas observaciones, otras fueron obtenido en Europa y otros lugares, y de la combinación de todos los Se obtuvo un conocimiento aproximado de la distancia al sol. Sin embargo, la discusión más completa de estas observaciones no lo hizo, Durará un tiempo. No fue hasta el año 1824 cuando la el ilustre Encke calculó la distancia del sol, y dio como resultado definitivo: 95.000.000 de millas.

Durante muchos años este número fue adoptado invariablemente, y muchos de los La generación actual recordará cómo se les enseñó en su Días escolares en los que el sol estaba a 95.000.000 de millas. Al final dudas empezaron a susurrarse sobre la exactitud de este resultado. Las dudas surgió en diferentes sectores y se les otorgaron distintos grados de importancia; Pero todos señalaban en una dirección, todos indicaban que la distancia del sol no era realmente tan grande como el resultado de que Encke había conseguido. Debe recordarse que existen varias formas de encontrar la distancia del sol, y será nuestro deber aludir a algunos otros métodos más adelante. Se ha comprobado que el resultado obtenido por Encke a partir de las observaciones realizadas en 1761 y 1769, con instrumentos inferiores a los modernos, eran demasiado grandes, y que el La distancia al sol probablemente ahora se indique en 92.000.000 de millas.

Me atrevo a relatar nuestra experiencia personal del último tránsito de Venus, que tuvimos la suerte de contemplar desde el Observatorio Dunsink la tarde del 6 de diciembre de 1882.

[pág. 185]

La mañana del día lleno de acontecimientos parecía ser igual de desfavorable para un gran espectáculo astronómico como se podía imaginar. Nieve, un un par de pulgadas de grosor, cubría el suelo, y más caía, con Pero poco intermedio, toda la mañana. Parecía casi desesperanzador que se podía obtener una visión del fenómeno desde ese observatorio; pero conviene en tales casos tener presente la orden judicial dada a la Observadores en una célebre expedición de eclipse. Les dijeron que no Importaba cómo debería ser el día, que fueran a hacer todo suyo los preparativos exactamente como lo habrían hecho si el sol brillara con Esplendor intacto. Por este consejo, sin duda muchos observadores han obtuvo beneficios; y actuamos con un éxito considerable.

En ese momento, en el observatorio había dos ecuatoriales, uno de ellos un instrumento viejo, pero bastante bueno, de unas quince pulgadas de apertura; el otro gran ecuatorial sur, de doce pulgadas de apertura ya referido. A las once en punto el día parecía peor que nunca; Pero nosotros en Una vez procedió a prepararlo todo. Aposté al señor Rambaut en la pequeña ecuatoriales, mientras yo mismo me encargué del instrumento Sur. La nieve seguía cayendo cuando se abrieron las cúpulas; pero, según nuestro Esquema preestablecido, los telescopios estaban dirigidos, no en realidad hacia el sol, pero al lugar donde sabíamos que estaba el sol, y el reloj era se pusieron en marcha que se propagaron por los telescopios, aún de forma constante apuntando hacia el sol invisible. El tiempo previsto del tránsito aún no había llegado.

El ocular empleado en el ecuatorial sur también debe recibir un informe aviso. Por supuesto, será evidente que el resplandor total del sol debe mitigarse considerablemente antes de que el ojo pueda verlo impunemente. La luz del sol cae sobre un trozo de cristal transparente inclinado en cierto ángulo, y la mayor parte del calor del sol, así como una cierta cantidad de luz atraviesa el cristal y se pierde. A Sin embargo, cierta fracción de la luz se refleja en el cristal, y entra en el ocular. Esta luz ya está muy reducida en intensidad, pero va mucho más lejos[pág. 186] reducción a nuestro antojo por un ingenioso Un artificio. El cristal que refleja la luz lo hace en lo que es llamado ángulo polarizador, y entre el ocular y el ojo es un plato de turmalina. Esta placa de turmalina puede girarse mediante el Observador. En una posición apenas interfiere con la luz polarizada en absoluto, mientras está en ángulo recto con ella, casi se corta Todo. Simplemente ajustando la posición de la turmalina, la el observador tiene el poder de representar la imagen de cualquier brillo que puede ser conveniente, y así se pueden realizar observaciones del sol con el grado adecuado de iluminación.

Pero tales aparatos parecían en esta ocasión una mera burla. El La turmalina ya estaba lista, pero hasta la una en punto ni rastro de sol se podía ver. Sin embargo, poco después de la una, nos dimos cuenta de que el El día se estaba aclarando; y, mirando hacia el norte, de donde viene el viento y la nieve llegaba, vimos, para nuestro inexpresable deleite, que el Las nubes se despejaban. Finalmente, el cielo hacia el sur comenzó a mejorar, y por fin, a medida que se acercaba el momento crítico, pudimos detectar el lugar donde el sol empezaba a aparecer. Pero el momento predicho llegaron y pasaron, y aún el sol no había atravesado las nubes, aunque cada momento la certeza de que lo haría se hacía más Evidente. Por tanto, se perdió el contacto externo. Intentamos consolar nosotros mismos por la reflexión de que esto no era, después de todo, un muy y esperaba que el contacto interno fuera más Exitoso.

Finalmente, las vigas que luchaban atravesaron la obstrucción, y vi el disco redondo y afilado del sol en el visor, y miró con ansia el punto en el que se centraba la atención. Ya habían pasado algunos minutos desde el momento previsto del primer contacto y, para mi alegría, vi la pequeña muesca en el margen del sol que indica que el tránsito había y que el planeta estaba entonces a un tercio del sol. Pero el El momento crítico aún no había llegado. Por la expresión "primer interno contacto" debemos entender el momento en que el planeta haya completado Entró *en* el sol. Este primer contacto estaba programado para ocurrir en veintiún años Actas[Pág. 187] más tarde de lo que ya se mencionó el contacto externo. Pero el Las nubes volvieron a decepcionar nuestra esperanza de ver el contacto interno. Mientras mirando fijamente la vista exquisitamente hermosa de la vista gradual adelantado del planeta, me di cuenta de que había otros objetos además de Venus entre yo y el sol. Eran los copos de nieve, que volvió a caer rápidamente. Debo admitir que el fenómeno fue singularmente precioso. El efecto telescópico de una tormenta de nieve con el sol como un un trasfondo que nunca había visto antes. Me recordó a la lluvia dorada que a veces se ve cayendo de una serie de cohetes aéreos durante espectáculos pirotécnicos; Con gusto habría prescindido el espectáculo, pues necesariamente se deducía que el sol y Venus desaparecieran de nuevo desde la vista. Las nubes se acumularon, la tormenta de nieve cayó tan fuerte como nunca, y apenas nos atrevíamos a esperar ver algo más; 1 pasaron 57 minutos, el primer contacto interno terminó, y Venus había entrado completamente en el sol. Solo habíamos obtenido una breve vista, Y aún no habíamos podido tomar ninguna medida ni nada observaciones que podrían ser útiles. Aun así, haber visto siquiera una parte de un tránsito de Venus es un evento para recordar toda la vida, y nosotros sintió más alegría de la que se puede expresar fácilmente incluso con ese leve brillo de éxito.

Pero aún les esperaban cosas mejores. Mi asistente vino con el informe que también había tenido éxito en ver a Venus en la misma fase que yo lo tenía. Ambos retomamos nuestros puestos, y a las dos y media las nubes empezaron a dispersarse, y la perspectiva de ver el sol empezó a mejorar. Lo fue Ahora no se trata de las observaciones del contacto. Para entonces, Venus era Bueno, en el Sol, y por lo tanto nos preparamos para hacer observaciones con el micrómetro acoplado al ocular. Las nubes finalmente se dispersaron, y en ese momento Venus había entrado tan completamente en el sol que el La distancia desde el borde del planeta hasta el borde del sol era aproximadamente el doble de diámetro que el planeta. Medimos la distancia del interior borde de Venus respecto al extremo más cercano del sol. Estas observaciones fueron repetidas tan a menudo como sea posible, pero cabe añadir que ellas solo se hicieron con muy[Pág. 188] considerable dificultad. El sol ya estaba muy bajas, y los bordes del sol y de Venus no eran ni mucho menos de eso carácter estacionario adecuado para la medición micrométrica. El el margen del luminario temblaba, y Venus, aunque sin duda lo era a veces circular, muy a menudo se distorsionaba hasta tal punto que hacía Las medidas son muy inciertas.

Conseguimos obtener dieciséis medidas en total; pero el sol sí Ahora, bajando el cuerpo, las nubes empezaron a interferir de nuevo, y vimos que La búsqueda del tránsito debe dejarse a los miles de astrónomos en climas más felices que lo habían esperado con ansias. Pero antes de que los fenómenos cesaron, me ahorré unos minutos a lo algo mecánico trabaja en el micrómetro para observar el tránsito en el más la forma pintoresca que presentaba el gran campo del buscador. El sol ya empezaba a ponerse los tonos rojizados del atardecer, y allí, lejos en su cara estaba el disco negro, redondo y afilado de Venus. Fue entonces fácil de simpatizar con la suprema alegría de Horrocks, cuando, en 1639, él por primera vez presenció este espectáculo. El interés intrínseco de El fenómeno, su rareza, el cumplimiento de la predicción, el noble problemas que el tránsito de Venus nos ayuda a resolver, todos presentes Nuestros pensamientos al mirar esta imagen agradable, una repetición de lo cual no volverá a ocurrir hasta que las flores estén floreciendo en junio de d.C. 2004.

La ocasión de un tránsito de Venus también ofrece la oportunidad de estudiando la naturaleza física del planeta, y podríamos escuchar brevemente Indica los resultados obtenidos. En primer lugar, una El tránsito arrojará algo de luz sobre la cuestión de si Venus es acompañado por un satélite. Si Venus estuviera acompañada por un pequeño cuerpo en cercanía, sería concebible que en circunstancias ordinarias El brillo del planeta aniquilaría el débil haz de rayos desde el minuto compañero, y por tanto el satélite permanecería descubierto. Por tanto, era un asunto de gran interés a examinar la proximidad del planeta durante el acto de tránsito. Si un satélite y la existencia de uno o más de estos cuerpos ha sido frecuentemente sospechaba—entonces sí[pág. 189] ser capaz de detectar contra los brillantes Fondo del sol. Se prestó especial atención a este punto durante los tránsitos recientes, pero no se encontró ningún satélite de Venus. Por tanto, parece muy poco probable que Venus pueda ser atendida por Cualquier globo complementario de dimensiones apreciables.

Las observaciones dirigidas a la investigación de la atmósfera rodear a Venus ha tenido más éxito. Si el planeta estuviera vacío de una atmósfera, entonces sería totalmente invisible justo antes comenzando a entrar en el sol, y recaía en total invisibilidad en cuanto se fue del sol. Las observaciones realizadas durante los tránsitos no están en conformidad con tales suposiciones. Se ha prestado especial atención a este punto en los últimos años tránsitos. El resultado ha sido muy notable y se ha demostrado en la de manera concluyente, la existencia de una atmósfera alrededor de Venus. Como El planeta se fue alejando gradualmente del sol, el borde circular del planeta extendiéndose hacia la oscuridad se veía delimitada por un arco circular de luz, y el Dr. Copeland, que observó este tránsito de forma muy favorable circunstancias, fue capaz de seguir al planeta hasta que lo hizo Sin embargo, falleció completamente del sol, momento en el que el globo en sí mismo invisible, estaba claramente marcado por el cinturón de luz que lo permitía estaba rodeada. Este círculo luminoso es inexplicable salvo por el suposición de que el globo de Venus está rodeado por una atmósfera Concha de la misma manera que la Tierra.

Se puede preguntar, ¿cuál es la ventaja de dedicar tanto tiempo y trabajar a un fenómeno celestial como el tránsito de Venus que ha tenido ¿Poco que ver con asuntos prácticos? ¿Qué importa si el sol es estar a 95.000.000 de millas de diferencia, o solo a 93.000.000, o cualquier otra ¿Distancia? Debemos admitir de inmediato que la investigación es muy escasa relacionadas con asuntos de utilidad práctica. Sin duda una persona fantasiosa podría argumentar que para calcular nuestros almanaques náuticos con perfecto Precisión Necesitamos un conocimiento preciso de la distancia al Sol. Nuestra El vasto comercio depende de una navegación hábil, y hay un factor necesario para el éxito es la fiabilidad del "Almanaque Náutico". El aumento[pág. 190] La perfección del almanaque debe tener alguna relación con el aumento Perfección en la navegación. Ahora, como nos dicen las buenas fuentes, en huyendo hacia un puerto en una noche tempestuosa, o en otro momento crítico En caso de emergencia, incluso un metro de espacio marino suele ser de gran importancia, así que Podría ocurrir que a la influencia infinitesimal de la El tránsito de Venus en el "Almanaque Náutico" se debe a la seguridad de un Valiente embarcación.

Pero el tiempo, el trabajo y el dinero gastados en observar el el tránsito de Venus debe defenderse realmente por motivos muy diferentes. Vemos en ella una fuente fructífera de información. Nos indica la distancia del sol, que es la base de todas las grandes mediciones de la universo. Gratifica la curiosidad intelectual del hombre mediante una visión de Las verdaderas dimensiones del majestuoso sistema solar, en el que se encuentra la Tierra se ve interpretando un papel digno, aunque aún subordinado; y conduce nosotros a una concepción de la escala asombrosa en la que se encuentra el universo construido.

It is not possible for us, with a due regard to the limits of this volume, to protract any longer our discussion of the transit of Venus. When we begin to study the details of the observations, we are immediately confronted with a multitude of technical and intricate matters. Unfortunately, there are very great difficulties in making the observations with the necessary precision. The moments when Venus enters on and leaves the solar disc cannot be very accurately observed, partly owing to a peculiar optical illusion known as "the black drop," whereby Venus seems to cling to the sun's limb for many seconds, partly owing to the influence of the planet's atmosphere, which helps to make the observed time of contact uncertain. These circumstances make it difficult to determine the distance of the sun from observations of transits of Venus with the accuracy which modern science requires. It seems therefore likely that the final determination of the sun's distance will be obtained in quite a different manner. This will be explained in Chapter XI., and hence we feel the less reluctance in passing any from the consideration of the transit of Venus as a method of celestial surveying.

We must now close our description of this lovely planet;[Pg 191] pero antes Al hacerlo, añadamos —o en algunos casos repitamos— algunos datos estadísticos En cuanto al tamaño y las dimensiones del planeta y su órbita.

El diámetro de Venus es de unos 7.660 millas, y el planeta no muestra ninguna una desviación medible respecto a la forma globular, aunque difícilmente podemos dudar que su diámetro polar debe ser realmente algo más corto que el diámetro ecuatorial. Este diámetro es solo unos 258 millas menor que la de la tierra. La masa de Venus es aproximadamente tres cuartas partes de la masa de la tierra; o si, como es más habitual, comparamos la masa de Venus con El Sol, debe representarse por la fracción 1 dividida entre 425.000. Cabe observar que la masa de Venus no es tan grande en comparación con su volumen, como cabría esperar. La densidad de Este planeta es aproximadamente 0,850 del que tiene la Tierra. Venus pesaría 4,81 multiplicado por una esfera de agua de tamaño similar. La gravedad en su La superficie será, en cierta medida, menor que la gravedad en el Superficie de la Tierra. Un cuerpo aquí cae dieciséis pies en un segundo; un cuerpo si cae en la superficie de Venus, caería unos tres pies menos. Es no parece improbable que el tiempo de rotación de Venus sea igual a el periodo de su revolución alrededor del sol.

La órbita de Venus es notable por la aproximación cercana que realiza A un círculo. La mayor distancia de este planeta al sol no exceder la distancia mínima en un uno por ciento. Su distancia media desde el El Sol está a unos 67.000.000 de millas, y el movimiento en la órbita equivale a una velocidad media de casi 22 millas por segundo, siendo todo el trayecto logrado en 224,70 días.