4. *Radiation.*—Radiation produces cold, because radiation is nothing else than giving off heat.

The earth, and all bodies on its surface, are continually radiating heat. This is compensated during the day by the heat received from the sun; in fact, the amount received is greater than that given off. But at night the reverse holds true, and a greater amount is radiated than is received. This cooling of the earth's surface is, as has been stated, the cause of dew and frost.

It is often said that it freezes harder when the moon shines than when it is concealed by clouds. This is the case, but the moon has nothing to do with the freezing. The true explanation of the phenomenon is this: When the moon shines, it is generally cloudless, and the radiation goes on more rapidly, and of course a greater degree of cold is produced. On the contrary, when the moon is obscured, it is generally cloudy; now the clouds are good radiators of heat, and the heat that they send back to the earth is nearly or quite enough to compensate for that radiated from the earth; hence the process of freezing is either retarded or entirely prevented.

Plants are good radiators, hence they are more likely to be affected by frost than other objects. To protect them from frost, we cover them with mats, which prevent radiation, or rather radiate back the heat that the plants throw off.

Explain radiation as a cause of cold. *Illustrate. What effect has the moon on freezing? Why is it colder when the moon shines than when cloudy? Why are plants likely to be affected by frost? How are they protected?*

CHAPTER VI.

OPTICS.

I.—GENERAL PRINCIPLES.

Definition of Optics.

257. OPTICS is that branch of Physics which treats of the phenomena of light.

Definition of Light.

258. LIGHT is that physical agent which, acting upon the eye, produces the sensation of sight.

Two Theories of Light.

259. Two theories have been advanced to account for the phenomena of light: *the Emission Theory*, and *the Wave Theory.*

According to the *emission theory*, light consists of infinitely small particles of matter, shot forth from luminous bodies with immense velocity, which, falling upon the retina of the eye, produce the sensation of sight. This is the theory of NEWTON and LAPLACE.

According to the *wave theory*, light consists of *waves*, or vibrations, transmitted through an impalpable medium

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(**257.**) What is Optics? (**258.**) What is Light? (**259.**) What two theories of light have been advanced? Explain the emission theory. Explain the wave theory.

of almost perfect elasticity, called *ether*. This medium pervades all space, and penetrating all bodies, exists in the interspaces between their molecules. Luminous bodies impart a motion of vibration to this ether, which is transmitted through it in the same way that sound is transmitted through the atmosphere, and reaching the eye, it produces the sensation of sight, just as sound falling upon the ear produces the sensation of hearing. This is the theory of HUYGHENS, FRESNEL, YOUNG, MALUS, and many others, and is the one now adopted by almost all physicists.

The vibrations, or waves, which constitute light, are far more rapid and much shorter than those which constitute sound, but the analogy between the two is extremely close. In both the intensity depends upon the excursions of the molecules. In sound, the pitch depends upon the frequency of the waves, whilst in light, colors depend upon the same condition, red corresponding to grave, and violet to acute sounds. This will be further considered hereafter.

Sources of Light.

260. Bodies which emit or give out light, are called *luminous bodies*. The different sources of light are the *sun*, the *stars*, *heat*, *chemical combinations*, *phosphorescence*, and *electricity*, if indeed the latter are not modifications of a common principle.

We know nothing of the cause of the light emitted by the sun and the stars. We do know, however, that bodies when heated become luminous, and their luminosity becomes greater as their temperature is raised. Thus, coal when heated becomes luminous emiting a glow; the same is the case with the metals.

Artificial light, like that of candles, lamps, gas lights, &c., is due to the combustion of substances containing carbon and hydrogen,

How do light vibrations compare with sound vibrations? What analogies exist between light and sound? (**260.**) What are luminous bodies? What are some of the sources of light? *What do we know of the causes of natural light? Of artificial light?*

which, combining with the oxygen of the air, produces a degree of heat so great that the burning bodies become luminous.

PHOSPHORESCENCE is a pale light, given out by certain substances in darkness, without any manifestation of heat. Phosphorescence is observed in animal and vegetable substances, and in some minerals. Certain insects also have the power of emitting a phosphorescent light; thus the surface of the ocean in many parts of the world is covered with an infinity of small animals, which become phosphorescent during the night, especially when disturbed. Certain minerals become phosphorescent when exposed for a long time to the solar rays, such as the diamond, white marble, fluor spar, &c.

The cause of phosphorescence is not known, but in many cases it appears to be the result of electrical excitement.

ELECTRICITY, as we shall see hereafter, is a source of light so intense, that it may be compared with the brilliancy of the sun.

Media.—Opaque and Transparent Bodies.

261. A MEDIUM is anything that transmits light; thus, free space, air, water, and glass, are *media*.

Media owe their property of transmitting light to the ether which pervades them. This ether exists in the spaces between the particles of all bodies, but not always in such a state as to permit the transmission of light.

A TRANSPARENT BODY is one which permits light to pass through it freely, as glass, diamonds, rock-crystal, and water.

When a body permits light to pass through it, but not in such quantity as to permit objects to be seen through them,

What is Phosphorescence? Illustrate. *What is its cause?* (**261.**) What is a Medium? Examples. *To what is the transmission of light through a medium due?* What is a Transparent Body?

they are called *translucent*. Thus, scraped horn, ground glass, oiled paper, and thin porcelain are translucent.

An OPAQUE BODY is one that does not permit light to pass through it. Thus, iron, wood, and granite are opaque bodies.

Absorption of Light.

262. No body is perfectly transparent; all intercept or absorb more or less light, but some absorb much more than others. If light is transmitted through great thicknesses of media which in thin layers are transparent, a quantity of light is absorbed, and it often happens that the transmitted light is not of sufficient intensity to produce the sensation of sight.

The atmosphere seems perfectly transparent, but it is a known fact that much of the light of the sun is absorbed in reaching the earth, as is shown by the greater brilliancy of the stars in the higher regions, as on mountain tops. In the high regions of the atmosphere, objects are more clearly seen than nearer the earth; indeed so great is the clearness of vision in these regions, that it becomes exceedingly difficult to judge of distances. Opaque bodies absorb all of the light falling upon them which is not reflected.

The physical cause of absorption of light by bodies is some peculiarity of molecular constitution, which breaks up and neutralizes the waves of light that enter them.

Rays of Light.—Pencils.—Beams.

263. A RAY of light is a perpendicular to the front of a wave.

A ray of light indicates the direction in which light is propagated, and along which it produces its effects.

When the ether is uniformly distributed throughout a medium,

A Translucent Body? An Opaque Body? (**262.**) Explain the phenomenon of absorption. *Effect of atmospheric absorption?* Physical cause of absorption? (**263**.) What is a ray of light?

the waves of light are concentric spheres, and the rays of light are straight lines, because a perpendicular to one wave front will be perpendicular to all of the successive stages of that front. Media, in which the ether is uniformly distributed, are, with respect to light, called *homogeneous*. All other media are called *heterogeneous*.

When the waves of light are not concentric spheres, the rays of light are curved. Such, for example, are the rays of light transmitted through the atmosphere.

A PENCIL OF RAYS is a small group of rays meeting in a common point, such as the rays proceeding from a candle or a lamp.

When the rays *proceed from* a common point, they are are said to be *divergent*. When they *proceed towards* a common point, they are said to be *convergent*.

A BEAM OF RAYS is a small group of parallel rays, such as enter a small hole in a shutter, from a distant body, as the sun

Velocity of Light.

264. It was shown by RŒMER, a Swedish astronomer, in 1678, that light occupies nearly $8\frac{1}{4}$ minutes in coming from the sun to the earth, which gives a velocity of 192,000 miles per second.

He ascertained the velocity of light by a succession of observations on the eclipses of Jupiter's first satellite. In Fig. 155, *S* represents the sun, *T*, the earth, *J*, Jupiter, and *e*, Jupiter's first satellite. The darkened portion of the figure beyond Jupiter represents the shadow of that planet cast by the sun. It is known by computation, that Jupiter's first satellite revolves about that planet once in 42 hours, 28 minutes, and 36 seconds, and by entering the shadow of Jupiter, is eclipsed at each revolution.

What is the direction of a ray in a homogeneous medium? What is a homogeneous medium? A heterogeneous medium? Direction of a ray in such a medium? What is a Pencil of Rays? Example. Convergent? Divergent? What is a Beam of Rays? Example. (**264.**) What is the velocity of light? By whom determined?

Rœmer found that as the earth moved from T, its nearest position to Jupiter, towards t, its most remote position, the interval between the consecutive eclipses of the satellite gradually grew longer, whilst in moving from t back again to T, these intervals grew shorter. The total retardation in passing from T to t, was found to be nearly $16\frac{1}{2}$ minutes, and the total acceleration in the remaining half of the earth's revolution was also found to be $16\frac{1}{2}$ minutes. This was accounted for by the fact that the earth was moving away from Jupiter in the first case, and therefore the

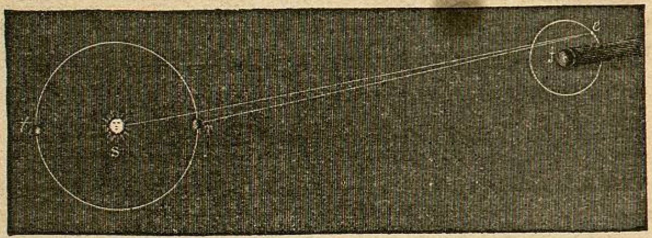

Fig. 155.

light had to travel further and further at each eclipse to reach the observer, whilst in the second case, the reverse happened.

Rœmer therefore inferred that it required $16\frac{1}{2}$ minutes for a ray of light to traverse the diameter of the earth's orbit, or $8\frac{1}{4}$ minutes for it to pass over the radius of that orbit, that is, over a distance equal to that of the earth from the sun.

Rœmer's deduction has been confirmed by observations made on the aberration of light, and also by direct experiment.

Explain the process of Rœmer's discovery. His deduction. Has it been confirmed?

It is difficult to conceive a velocity so great as 192,000 miles per second, a speed that would carry a ray of light around the earth eight times in a single second of time. Some idea, however, may be had of the velocity of light, from the fact that it would require more than two and a half centuries for one of our most rapid express trains of cars to run a distance over which light passes in $8\frac{1}{4}$ minutes.

It takes light more than four hours to reach us from Neptune, the most distant of the planets of our system, and it is capable of proof that light occupies more than three years in coming to us from the nearest of the fixed stars. Now, if astronomers are right in the inference that the remotest stars visible in our telescopes are more than a thousand times as distant as the nearest ones, then indeed must the light that makes us aware of their existence, have set out on its journey long centuries before the beginning of the Christian era. These conclusions serve to show the vastness of the material universe, and the comparative littleness of our own planet.

Intensity of Light.—Photometry.

265. The Intensity of Light is the amount of disturbance which it imparts to the ether. It can be shown mathematically, for light coming from the same sources, that *the intensity varies inversely as the square of the distance from its source.*

Hence we see that light follows the same law, with regard to its intensity, that is observed for gravity and sound. The law of variation of intensity can be verified, experimentally, by means of an instrument called a *photometer.*

A Photometer is an instrument for comparing the intensities of different lights.

Several different instruments have been devised for this purpose, one of the simplest being that shown in Fig. 156.

It consists of a vertical screen of ground glass, A, and a vertical solid rod, B, situated a short distance in front of it.

Give some illustrations of the immense velocity of light. (**265.**) What is the Intensity of Light? How does it vary with the distance? What is a Photometer? Explain the one shown in Fig. 156.

If two equal lights are placed at equal distances from *B*, it is found that the shadows which *B* casts upon *A*, are of the same tint. If one light be placed at any distance, and four

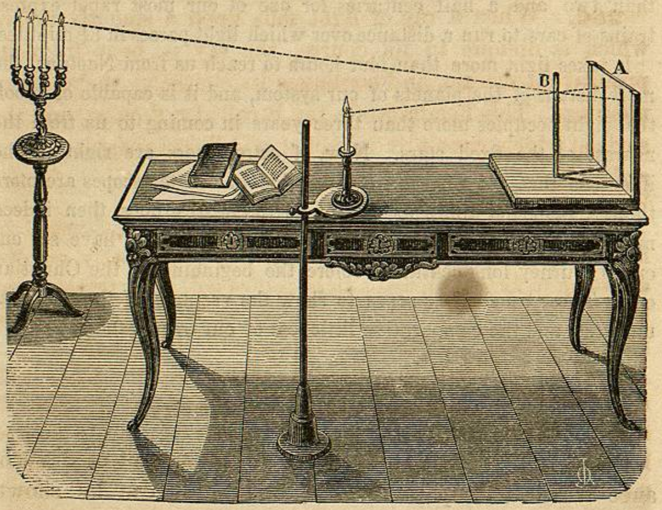

Fig. 156.

equal lights be placed at twice the distance, the shadows will be of the same tint; this is the case shown in the figure. It will require nine equal lights at three times the distance, sixteen at four times the distance, and so on, to produce the same effect. This experiment confirms the law of variation of intensity according to the inverse square of the distance.

To use the photometer to compare the intensities of any two lights, let them be placed, by trial, at such distances from *B*, that the shadows cast on *A* are of exactly the same tint; then will their intensities be to each other inversely as the squares of their distances from the rod, *B*.

How is the photometer used?

II.—REFLECTION OF LIGHT.—MIRRORS.

Reflection of Light.

266. When a ray of light falls upon a smooth surface which is oblique to its course, the ray is bent from its primitive direction, and continues its course in the original medium. This bending of a ray is called *reflection*, and the surface which causes it is called a *reflecting surface*, or a *reflector*.

When light falls upon a surface, one portion will, in general, be irregularly reflected, a second portion will be regularly reflected according to fixed laws, and a third portion will enter the body and be transmitted or absorbed. The portion which is reflected depends upon the polish of the surface and the obliquity of the light.

That portion which is irregularly reflected, is diffused in all directions, and plays a prominent part in the phenomena of vision. It is by means of this diffused light that we are enabled to see non-luminous bodies; it is also in consequence of this diffused portion that bodies appear to have color. Bodies of all colors, black as well as white, are all invisible in a dark room, and it is only when light falls upon them and is irregularly reflected, that they become visible and appear to have color.

It is the diffused light reflected by the clouds, the air, the earth, and objects upon it, that illuminates our rooms and renders objects visible which do not receive the direct rays of the sun.

If we look out from our houses we see objects clearly by means of this diffuse light, because they receive much light, and therefore reflect much; but if we look from without into a house, we see objects with less distinctness, because they receive but little light, and therefore they reflect but little.

It is now proposed to explain the laws of regular reflection.

(**266.**) What is reflection of light? What is a reflector? *When light falls upon a surface, into how many parts is it divided? Explain the action of each part. On what does the reflected portion depend? By which do we see bodies? Illustrate. Give examples.*

Definitions of Terms.

267. The ray that falls upon a reflecting surface is called *the incident ray;* thus, *CD*, Fig. 157, is an incident ray.

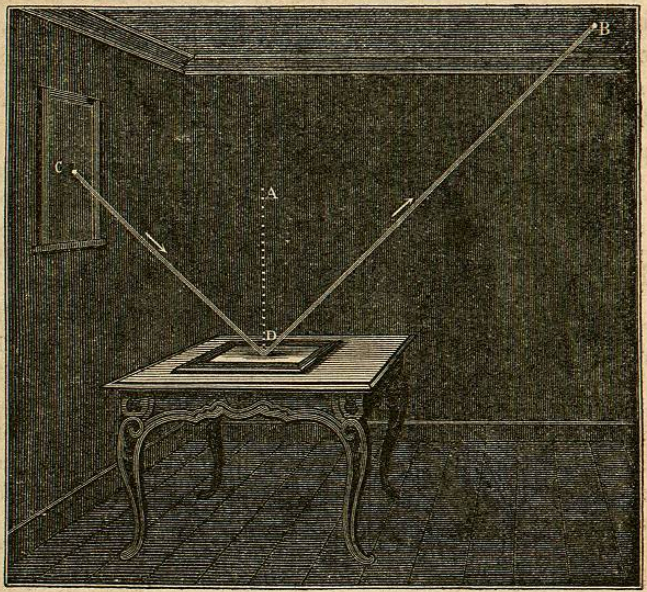

Fig. 157.

The point where the incident ray meets the reflecting surface, is called *the point of incidence;* thus, *D* is a point of incidence.

The angle which the incident ray makes with the normal to the reflecting surface at the point of incidence, is called *the angle of incidence;* thus, *CDA* is an angle of incidence.

(**267.**) What is an incident ray? Example. The point of incidence? Example. The angle of incidence? Example.

The plane which passes through the incident ray and the normal is called *the plane of incidence;* thus, the plane through *CD* and *DA*, is a plane of incidence.

The ray driven off from the reflecting surface is called *the reflected ray;* thus, *DB* is a reflected ray.

The angle which the reflected ray makes with the normal is called *the angle of reflection;* thus, *BDA* is an angle of reflection.

The plane of the reflected ray and the normal is called *the plane of reflection;* thus, the plane of *BD* and *DA* is a plane of reflection.

Laws of Reflection.

268. The following laws are shown by theory, and confirmed by experiment:

1. *The planes of incidence and reflection coincide;* both are normal to the reflecting surface at the point of incidence.

2. *The angles of incidence and reflection are equal;* this is true whatever may be the angle of incidence.

Direction in which objects are seen.

269. Whenever the rays of light proceed directly from an object to the eye, we see the body exactly where it is. When by reflection, or any other cause, the rays are bent from their primitive direction, we no longer see bodies in their proper position. They appear to be in the direction from which the ray enters the eye.

This is illustrated in Fig. 158. *A*, represents a body from which a ray of light, proceeding in the direction *AB*, is deviated or bent at *B*, so as to assume the new direction, *BC*. The eye receives the ray from the direction *BC*,

The plane of incidence? Example. The reflected ray? Example. The angle of reflection? Example. The plane of reflection? Example. (**268.**) What is the first law of reflection? What is the second law of reflection? (**269.**) In what direction do objects appear to the eye? Illustrate.

and in consequence the object, *A*, appears to be situated at

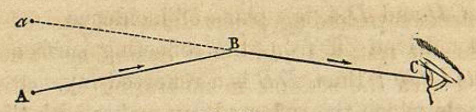

Fig. 158.

some point, *a*. This principle is of importance in explaining certain phenomena produced by reflectors and lenses.

Mirrors.

270. A MIRROR is a body with a polished surface, employed to form images of objects presented to it.

The best reflecting surfaces are those of polished metals. Our ordinary looking-glasses are composed of plates of smooth glass, upon the back of which is fastened a thin layer of tin and quicksilver.

This mixture, called an amalgam, offers an excellent reflecting surface, and it is from it that the principal reflection takes place. The glass serves to give the proper smoothness to the amalgam, as well as to protect it from injury and tarnish. There is, however, a reflection from the outer surface of the glass, giving rise to feeble images, which renders such reflectors objectionable for optical purposes. Hence it is, that reflectors for telescopes, and the like, are generally made of alloys, or mixtures of hard metals, which admit of a high polish. Such a mirror is called a *speculum.*

Mirrors are of two kinds, *plane* and *curved.*

Plane Mirrors.

271. A PLANE MIRROR is one in which the reflecting surface is plane.

(**270.**) What is a Mirror? What are the best reflecting surfaces? What are looking-glasses? Explain their construction? What is a speculum? How many kinds of mirrors are there? What are they? (**271.**) What is a Plane Mirror?

We have an example of plane mirrors in the ordinary looking-glasses of our houses. The surface of still water, which reflects surrounding objects, also the surface of quicksilver, when at rest, are additional examples. The latter is often used with the sextant in measuring the altitudes of the stars; it is also used in adjusting astronomical instruments.

Images formed by Plane Reflectors.

272. An IMAGE of an object is a picture or representation of that object, formed by a reflector, or by a lens.

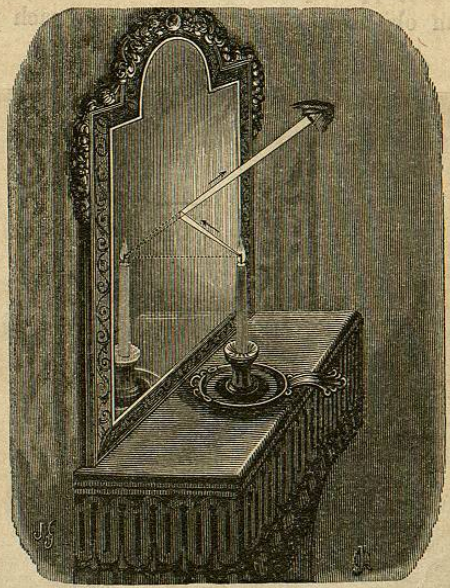

Fig. 159.

The manner of forming images by plane reflectors is illustrated in Fig. 159. A pencil of rays coming from a

Give examples. (**272**) What is an Image of an object? Explain the manner of forming the image of a point.

candle, is reflected so as to reach the eye. Because the angles of incidence and reflection are equal (Art. 268), each ray will have the same inclination to the mirror after reflection that it had before incidence. Hence the reflected rays, on being produced back, will meet at a point as far behind the reflector as the point of the candle is in front of it. Now, because the eye sees objects in the direction from which the rays come to it (Art. 269), the point appears to be as far behind the mirror as it really is in front of it. The representation of the point, seen in the glass, is its image.

What has been said of a single point is true of all points. Hence, if we suppose pencils of rays to proceed from every point of an object, as shown in Fig. 160, each point will

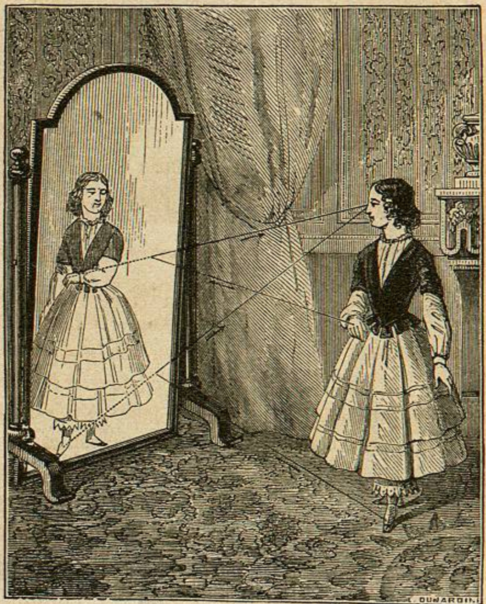

Fig. 160.

Explain the manner of forming the image of an object.

have its own image as far behind the mirror as the point is in front of it. The assemblage of these images of points makes up the image of the object.

Nature of the Images formed.

273. It will be seen from an inspection of Fig. 160, that the image of the child's right hand is on the left of the image in the glass, and that the image of the child's left foot is on the right of the image in the glass, that is, the image is reversed laterally. This comes from the fact, that the image of each point is as far behind the mirror as the point is in front. Hence we say, that *the object and the image are symmetrically situated with respect to the mirror.*

We see also from what has been said, that *the image is erect, and equal in size with the object.*

The rays that reach the eye *appear* to come from an image which does not in reality exist. The image is only *apparent.* Such images are called *virtual.*

A Virtual Image is an image which appears to exist, and which would be found by producing the deviated pencils of rays backwards, till they meet in points.

Multiple Images from Looking-glasses.

274. Metallic mirrors, or *specula,* as they are called, having but one reflecting surface, form but a single image. Glass mirrors have two reflecting surfaces, the front surface of the glass, and the metallic surface at the back of the glass. An image is formed by each of these surfaces, but that formed by the latter is the most striking, because the first surface reflects only a small portion of the light.

This formation of two images by glass mirrors renders them unfit for many optical purposes. The double image, formed by placing a point against the glass, enables us to judge of the thickness of the glass.

(**273.**) How are the object and its image by a plane reflector situated? Is the image real or apparent? Why? What is a Virtual Image? (**274.**) *Why do glass mirrors form two images? What is the objection to this duplication? How do we judge of the thickness of glass?*