—"*With inverted torch and swimming eyes,*
Sinks the fair shade of Mortal Life and dies".

LECTURES AT HOME,

BY

MARIA HACK.

LONDON.

DARTON AND HARVEY.

LECTURES AT HOME.

DISCOVERY AND MANUFACTURE OF GLASS:

LENSES AND MIRRORS:

THE STRUCTURE OF THE EYE.

BY MARIA HACK.

"Why should not children be instructed in those wonderful works of Nature and Art, which we daily use without ever reflecting how they are produced?"—Rollin.

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TO

MARY AND HER COMPANIONS,

THESE LECTURES,

WHICH WERE WRITTEN FOR THEIR

ENTERTAINMENT,

ARE AFFECTIONATELY INSCRIBED,

BY

THE AUTHOR.

THE design of this little book is so obvious, that any farther illustration of it seems unnecessary. The writer had purposed extending her plan to many other subjects likely to prove interesting to young persons, but was prevented by unforeseen circumstances. She is conscious that the Lectures which have been completed are very imperfect, but is encouraged, by the opinion of some who have had much experience in education, to hope, that notwithstanding these deficiencies, they may be found useful in awakening attention, and exciting a desire to obtain farther information.

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THE EYE.

LECTURE I.

DISCOVERY AND MANUFACTURE OF GLASS.

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PIECES OF FLINT, PLATE, CROWN, BROAD, AND COMMON GREEN OR BOTTLE-GLASS;—ALSO THE BULL'S-EYE FROM A TABLE OF CROWN-GLASS.

LECTURE I.

DISCOVERY AND MANUFACTURE OF GLASS.

While attending some of the interesting public Lectures we have lately heard, I regretted that, from the want of previous information, which is seldom obtained in very early life, the younger part of the audience were not likely to receive all the pleasure which that popular mode of imparting knowledge is calculated to afford. I could not help thinking, what a good thing it would be to have a course of easy, simple lectures, written expressly for young people, on the principle of supposing them to be entirely unacquainted with the subject treated of. Every thing must then be explained from the very beginning; and it would be found that many curious circumstances and interesting facts are to be known, respecting even the most common things—things which we are seeing and using every day with perfect indifference; whereas, did we understand something of their nature, or know what perseverance and ingenuity have been exercised to make them what they are, a new field of inquiry and observation would open before us, and we should be continually presented with fresh objects of rational curiosity.

I should have been very glad, for your sakes, if some better qualified person would undertake the task; but not knowing any one likely to do this, I have endeavoured to prepare a few very simple lectures for you. I think they will be intelligible even to the youngest of the present company; but if any explanation does not seem perfectly clear, you must stop me, and I shall be very happy to make it plainer if I can.

We have, in this little cabinet, a number of specimens, sufficient to engage our attention for a great many evenings; but I shall only speak of one of them to-night. We must, however, pursue some kind of method. I will therefore begin by observing, that all the substances contained in this cabinet, indeed every substance with which we are acquainted, may be divided into two classes. They are natural or artificial bodies.

By a *natural* body, I mean something which was made such as we see it by the power and wisdom of God.—An *artificial* body became what it is by the art and contrivance of man.

Here is a piece of glass; do you call it a natural or an artificial substance? Take it into your hands, and examine it;—what qualities can you discover by the sense of feeling?

It is hard, smooth, and cold.

And what can the eye observe?

The surface is bright, as well as smooth.

There is also another property of which the eye can judge—the peculiar property which makes glass so useful: I think I need not tell you what it is. But can you tell me the word by which people usually express this property, this clearness of substance, which enables you to see through the glass, to discern objects beyond it, as if the glass were not there?

We say, glass is *transparent;* but perhaps you do not thoroughly understand why the word transparent is so very expressive of this clearness; it is borrowed from the Latin, and has no meaning to English ears till the sense of it is explained: *trans* means beyond, on the other side; and *parent* is taken from another Latin word, which means to appear; so that a substance is *transparent* when objects *appear on the other side of it;* that is, when we can look *through* the substance.

If I wet my finger, and pass it round and round the edge of this tumbler, which is partly filled with water, you will be sensible of another property in glass—you now hear a musical tone: those who attended Mr. Addams' Lectures, and saw him draw the bow of a violin over the edge of several glass vessels, heard a very pleasing variety of musical tones. Substances which can be made to produce loud and shrill sounds are called *sonorous* bodies.

Glass, then, has properties which are evident to three of our senses.—Touch discovers that it is hard, smooth, and cold: Sight, that it is bright and transparent: Hearing, that it is sonorous. Taste discovers nothing, therefore we call it *insipid.* Smell discovers nothing, therefore we say that glass is *inodorous.* The syllable *in* is also borrowed from the Latin, it expresses the absence of a quality:—*in*sipid, without taste; *in*odorous, without smell.

Now that we have examined such qualities of glass as are obvious to our senses, and determined that it belongs to the class of artificial substances, (i. e. those which have been brought into their present form by the art of man,) perhaps you may like to know how he came to find out the way of making it. And here we must observe a great distinction between the works of man and the works of God. There is only *one* Creator. Every thing we see, whether it be what is called a natural substance or an artificial one, owes its origin, its first state, to the power and wisdom of the one great Creator.

This little cabinet before us is an artificial body, it was made by the art of man; but he used for the purpose part of a mahogany-tree, which probably came from one of the West Indian islands; or the countries on the Western shores of the Gulf of Mexico: this piece of wood, then, was part of a graceful tree with many branches, smooth, shining leaves, something like those of a laurel, and bunches of small, whitish flowers. I need not tell you whose power made the mahogany-tree, but I wish to impress upon you the vast, immeasureable distance between man, who can only shape and mix together the substances that he finds already made, and the Great Almighty Being who *creates* these substances, and gives man sense to make use of them. The one subsists by Himself; He has need of nothing: the other, for every thing he uses, for his life, and for what he calls his own cleverness, is indebted to God.

Man is also indebted to his Creator in another way, which he is very apt to overlook or forget. God governs the world by his providence. He knows every thing that happens, and appoints or directs events for the benefit of his creatures. Many very useful discoveries have arisen from circumstances which were quite unexpected, which man could not have contrived; therefore he should be thankful when such circumstances happen, and not take all the merit to his own cleverness.

In two of the entertaining Lectures we have lately heard, allusion was made to the accident, or unforeseen circumstance, which is supposed to have led to the discovery of glass. The story is this: Pliny (the same Pliny who was so remarkable for his love of natural history, and whose eager curiosity to observe the effects of that eruption of Vesuvius, which destroyed the city of Herculaneum, cost him his life) relates, that some merchants, being overtaken by a storm, were driven into the mouth of the river Belus, in Syria. Whether they were shipwrecked

I cannot tell you, but the merchants were obliged to continue there for some time; and they dressed their food at a fire kindled on the white, glittering sand, which formed the shore of the river. A plant called *kali* grew there abundantly, and was of course burned to ashes. These ashes mixing with the bright, hard sand, which was melted by the heat of the fire, produced a substance believed to have been till then unknown, which has since been called GLASS. Such is the account of Pliny: he also says, that the accident becoming known in that country, the people of Sidon, a neighbouring sea-port town of Phœnicia, applied themselves to repeating the experiment, and were successful.

The first glass-houses mentioned in history, were erected at Tyre, another city on the same coast, which was famous in ancient times for its commerce and manufactures; and there the art seems to have been practised for many ages before other countries attempted it.*

Now let us suppose that a party of ignorant

* Ency. Brit. Art. *Glass.*

The Discovery of Glass.

To face Page 10.

savages, who had gone out fishing in their canoe, had been driven by a storm into the river, and had kindled a fire on that beach of fine, white sand. Suppose the accident the same in all its circumstances, and the story differing only in the characters of those who witnessed the production of this new substance. But can we think the *result* would have been the same? That the savages would have reflected upon the subject, or have contrived the means of producing a similar substance at pleasure? To me it seems very unlikely; though I am ready to grant, that one of the most lively and observing of the party might be attracted by the bright appearance of the glass, might take it up, perceive its transparency, and amuse himself by spying through it at the sun, or the countenances of his companions, if indeed the glass were sufficiently transparent, which is not very likely, as the ashes of the burned weed must be mixed with glass produced in that accidental manner. Here, then, would have been an end of the adventure; and the world, in all probability, as little benefited as if the circumstance had never happened. But the enlightened Phœnicians did not view the new production with idle wonder. However dark and dingy, or speckled by the mixture of ashes, it might be, they perceived it was something worth thinking about, worth contriving means to free it from these impurities.

Now, if you had been in their place, and seen this curious substance, bright and transparent in some parts, in others opaque and disfigured by dirty particles, would it not have been your wish to obtain from the kali that property, whatever it might be, which had such a marvellous effect on the sand of the beach?

You know that hot water has the power of extracting the virtues of many plants; we see this every day, in making tea and coffee, in brewing beer, and many other instances. I believe the Phœnicians went upon this plan, for they succeeded, and in all probability by the method which is still practised in that country. The kali is cut down in the summer-time, and after being dried in the sun, it is burned; the ashes are then pounded, sifted, and boiled in coppers for a long time; as the water wastes in boiling, the liquid grows thicker, and at length a kind of salt begins to be formed, and to shoot forth little crystals These are taken out of the copper with ladles, put into vessels to drain, and afterwards coarsely pounded and dried in an oven. The salt is then ready to be mixed with sand; and being freed from all its impurities, the application of sufficient heat will produce clear glass.

Let us now observe the situation of the Phœnicians who had made this grand discovery. They lived here on the shores of the Mediterranean, and Tyre and Sidon were their chief cities: in the interior of the country was that extensive chain of wooded hills called Mount Lebanon, whence they were abundantly supplied with timber. The Phœnicians employed it in building ships; they were the first navigators, and also the merchants of those ancient times—sailing from one country to another, and exchanging their own commodities for the products of other lands. They possessed the materials and the knowledge necessary for building ships; and they were masters of the art of writing, which enabled them to send orders to their agents at a distance. This map shows how favourably they were situated for becoming merchants. The other nations who were beginning to be civilized, also lived on the shores of the Mediterranean. Here were the inhabitants of Asia Minor—here the Greeks—here the Romans: on the African side were the Egyptians and Carthaginians: with all of these the Mediterranean, that *sea in the middle of the earth*, afforded a ready communication, but the adventurous Phœnicians did not confine themselves within its limits; they passed the Straits of Gibraltar, and pursued their course to the southern shores of England, where they opened a trade with the natives, for the tin found in the rocks of Cornwall. The Britons were then very ignorant, and could do but little for themselves; the Phœnicians supplied them with earthen vessels, and very probably with trinkets of glass.

Thick rings of glass, of different colours, and sometimes curiously streaked, were common in Britain at the time it was invaded by Julius Cæsar. The Britons called them *glass adders;* and they are supposed to have been worn as amulets, or charms, to preserve the wearer from sickness or misfortune. From the circumstance of their possessing these rings, it has been conjectured by some, that the Britons themselves were acquainted with the art of making glass; but their ignorance at that period renders this highly improbable, and I cannot find that our best historians mention the circumstance. It is more likely that the glass rings were given by the Phœnicians, in exchange for the native tin ore of England.*

In the same way it is probable that these primitive merchants exchanged their glass toys for the linen of Egypt, as the mummies found in the catacombs of Memphis are adorned with glass beads. Some of you perhaps do not know that those mummies are the bodies of ancient

* Ency. Brit.

Egyptians, preserved from decay by a curious process; and which, after being carefully wrapped up in many bandages, were placed in catacombs, or subterraneous galleries, of which there are vast numbers in Egypt. I have heard that the mummies of Memphis are supposed to have been deposited there before the birth of Moses;* i. e. between three and four thousand years ago. If you have not read, you would be amused by some verses addressed to one of these mummies, in which the poet rapidly enumerates many historic events and revolutions, which have taken place since the period when it may be supposed that this Egyptian was embalmed, and placed in the catacomb among his deceased ancestors.†

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* Gray's Op. Chemist, p. 554.

† To the Mummy at Belzoni's Exhibition.

And thou hast walked about (how strange a story)
In Thebes's streets, three thousand years ago,
When the Memnomium was in all its glory,
And Time had not begun to overthrow
Those temples, palaces, and piles stupendous,
Of which the very ruins are tremendous.

If the Phœnicians brought any of their glass manufactures into Egypt so early as has been conjectured, we may conclude that vessels, or ornaments of this substance were not in common use, or they would most likely have been mentioned by some of the writers of the Old Testament. There is, indeed, one passage in Exodus, where Moses is said to have made the laver of brass *of the looking-glasses of the women.*

Speak! for thou long enough hast acted dummy!
  Thou hast a tongue,—come, let us hear its tune;
Thou'rt standing on thy legs above-ground, Mummy
  Revisiting the glimpses of the moon,
Not like thin ghosts, or disembodied creatures,
But with thy bones and flesh, and limbs and features.

Tell us, for doubtless thou canst recollect,
  To whom we should assign the sphinx's fame:
Was Cheops or Cephrenes architect
  Of either pyramid that bears his name?
Is Pompey's pillar *really* a misnomer?
Had Thebes a hundred gates, as sung by Homer?

Perhaps thou wert a Mason, and forbidden,
  By oath, to tell the mysteries of thy trade;—
Then say what secret melody was hidden
  In Memnon's statue, which at sunrise played.
Perhaps thou wert a priest!—if so my struggles
Are vain, for priestcraft never owns its juggles.

This is evidently an error of the English translators, who being accustomed to use the words mirror and looking-glass to express *the same thing*, did not consider that it was impossible for Moses, or any other man, to make a brass washing-basin out of looking-glasses: it seems strange that the mistake did not strike them; and stranger still, that it should yet remain uncorrected in our Bibles. The mirrors of the ancients

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Perchance that very hand, now pinioned flat,
 Has hob-a-nob'd with Pharoah, glass to glass;
Or dropped a halfpenny in Homer's hat;
 Or doff'd thine own, to let queen Dido pass;—
Or held, by Solomon's own invitation,
A torch at the great temple's dedication.

I need not ask thee if that hand, when armed,
 Has any Roman soldier mauled and knuckled;
For thou wast dead and buried, and embalmed,
 Ere Romulus and Remus had been suckled;—
Antiquity appears to have *begun*
Long after thy primeval race was run!

Thou couldst develope, if that withered tongue
 Could tell us what those sightless orbs have seen,
How the world looked when it was fresh and young,
 And the great Deluge still had left it green;
Or was it then so old that history's pages
Contained no record of its earlier ages?—

were made of plates of some polished metal: silver was preferred for the purpose; but when they were so large as to reflect the whole figure, they were formed of thin plates of some inferior metal, silvered over. A white metal, composed by mixing copper and tin, was also used for the purpose; and as such mirrors soon became dim, it was customary to keep a sponge and some pounded pumicestone beside them, in

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Still silent! uncommunicative elf!
  Art sworn to secresy? Then keep thy vows;
But prithee tell us something of thyself,
  Reveal the secrets of thy prison-house;
Since in the world of spirits thou hast slumbered,
What hast thou seen? What strange adventures numbered?

Since first thy form was in this box extended,
  We above ground have seen some strange mutations;
The Roman Empire has begun and ended;
  New worlds have risen, we have lost old nations,
And countless kings have into dust been humbled,
While not a fragment of thy flesh has crumbled.

Didst thou not hear the pother o'er thy head,
  When the great Persian conqueror, Cambyses,
Marched armies o'er thy tomb, with thundering tread;
  O'erthrew Osiris, Orus, Apis, Isis,
And shook the Pyramids with fear and wonder,
When the gigantic Memnon fell asunder?

order to renew the polish when needful. The mirrors of the Hebrew women seem to have been made of brass, by the use to which Moses applied them.

We have no account of glass being made among the Romans till the reign of Tiberius, who was emperor at the time our Saviour was on earth; i. e. about eighteen hundred years since. At that time glass was not generally

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If the tomb's secrets must not be confessed,
  The nature of thy private life unfold;
A heart has throbbed within that leathern breast,
  And tears adown those dusty cheeks have rolled.
Have children climbed those knees and kissed that face
What was thy name and station, age and race?

Statue of flesh!—Immortal of the dead!
  Imperishable type of evanescence!
Posthumous man! who quitt'st thy narrow bed,
  And standest undecayed within our presence!
Thou wilt hear nothing till the judgment morning,
When the great trump shall thrill thee with its warning.

Why should this worthless tegument endure,
  If its undying guest be lost for ever?
O! let us keep the soul embalmed, and pure
  In living virtue! that when both must sever,
Altho' corruption must our frame consume,
The immortal spirit in the skies may bloom.

H. SMITH.

known or used by the Romans: they preferred drinking out of gold or silver vessels, and had no glass windows till the reign of Nero.*

After the destruction of the Roman empire, which included under its dominion all the ancient nations I have mentioned as inhabiting the shores of the Mediterranean, another nation of merchants rose to wealth and power, by the commerce they established on that sea, which was still the bond of union between the most civilized countries. You have heard, perhaps,

"From dirt and sea-weed how proud Venice rose;"

and no doubt you have seen the representations of its splendid churches and palaces, in some of the annuals. It was the wealth acquired by commerce that enabled the Venetians gradually to convert a cluster of small islands, once inhabited only by a few poor fishermen, into a magnificent city. The Phœnicians, as I said before, were the merchants of ancient times: the citizens of Venice were the merchants of that period called *the middle ages*, from occupying the space

* Ency. Brit.

between ancient and modern history. You all know who are the merchants of *modern times;* what nation it is whose commerce is more extensive than that of any other people, and who have raised *another cluster of islands* to an extraordinary degree of wealth and power, by means of the trade they carry on with the whole of the civilized world.

The middle ages are sometimes called the *dark ages,* because the ancient learning was then so much forgotten or neglected, that the greater part of Europe relapsed into an almost barbarous state, and was lost in the darkness of ignorance: but even then, the desire of obtaining wealth operated as an excitement to ingenuity, and some arts were practised with success. The Venetians, for instance, resembled the ancient merchants, not only in the spirit of commercial enterprise, but in paying great attention to the manufacture of glass.

In the thirteenth century, when Henry the Third and Edward the First reigned in England, the Venetians excelled all the other people of

Europe in making glass, and were in sole possession of the art of forming it into looking-glasses. Three hundred years afterwards, the English began to try for themselves; and gradually improved in the art, till they brought it to the present state of perfection. The French also exercised their ingenuity, by the invention of a method of casting very large plates for looking-glasses,* in size resembling those described by the poet Cowper,

> " In which he of Gath,
> Goliah, might have seen his giant form
> Whole, without stooping, towering crest and all."

You will now, I hope, recollect the circumstances which led to the discovery of this useful art, and that the first glass was composed of sand and the ashes of the kali. As the art of making glass improved and begun to be practised in other countries, it was found that several plants beside kali would, after burning, yield a salt fit for the glass-maker. They are mostly maritime plants, or growing on sandy shores;

* Ency. Brit.

they have the general name of salsola, or salt wort, from the salt which they yield; but the quality of the salt varies, either from the peculiar nature of the plants employed, or the manner of preparing the salt, which is distinguished by different names: one species, growing in the South of France and in Spain, produces a salt called *barilla,* which is an impure kind of soda. Another plant, which is found abundantly on the Spanish shores of the Mediterranean, affords all the best soda that is used in Europe. Here is a piece of it, which I think you will like to examine: if you taste it, you will find a peculiar and unpleasant flavour, which is common to these salts; they have likewise a name, common to them all—*alkalis,* from kali, the Arabic name of the plant from which the Phœnicians first obtained it.* I will not now mention the other properties of alkalis, because we are thinking about glass, and had better confine our attention to it, and the ingredients used in making it.

* Ure's Dictionary of Chemistry, p. 135.

Having shown you a specimen of the salt employed in glass-making, I will now direct your attention to one species of that useful family of plants which produce it. I sent for it on purpose for this Lecture, thinking that some of you might not, perhaps, be acquainted with the plant; and that, if others had seen it lying on the beach, they might not be aware of its use and value. It is a kind of fucus. In Latin, that word signifies *paint;* and it was probably applied to these plants, because a pigment, staining red, is obtained from some species of fucus. This kind is called fucus vesiculosus, from its vesicles or bladders filled with air. During the summer the bladders are filled with a viscid, jelly-like substance, which is sometimes applied to scrofulous swellings, and thought to be efficacious. This plant is found on all the coasts of the British islands; the salt obtained from it is called potash or kelp. Some of you may, perhaps, have observed, that the rocks at Bognor, which are bare at low-water, are almost covered with this plant: when quite fresh, it is of an olive-green colour, and looks much prettier than in its present state. The salt it yields is of so much importance in commerce, that, on shores where it does not abound, it is sometimes raised artificially, by depositing stones at regular distances. The fuci will then spring up of themselves, and in four years yield a crop fit for cutting.*

Hitherto I have spoken only of *alkaline salts* and *sand,* as entering into the composition of glass. As the art advanced towards perfection, it was found that some other materials might be used with advantage; and that, by varying the mixture, several kinds of glass, suitable for different purposes, might be obtained.

We have specimens of the five kinds of glass at present manufactured, on the table before us.

In this tumbler we have an example of *flint-glass.*

Here is a piece of *plate-glass.*

This is the best kind of window-glass, called *crown-glass.*

* Loudon's Ency. of Plants, p. 946.

This is an inferior article, for the same purpose, called *broad-glass*.

And here is a piece of common bottle, or coarse green glass.*

You see that each of these varieties differs considerably from the other specimens; this difference arises partly from the ingredients, and partly from the method employed by the manufacturers. If you wish to understand these distinctions, I will endeavour to explain them as familiarly as I can; and after we have noticed the principal substances and methods employed in making the different kinds of glass, we may consider the uses to which they have been applied, and observe how much the knowledge and happiness of man have been increased by the discovery. All this, however, would be too much for one evening.

Let us now go back to the first glass, which was accidentally made by the melting and running together of the sand on the shore of the Belus, and the salt contained in the ashes of the

* Ure's Dictionary of Chemistry, p. 505.

plant kali. The sand composed the body or substance of the glass—the use of the kali was to make the sand melt more readily.

Substances that are added to minerals to assist the power of fire in melting them, are called *fluxes,* and for a very plain reason. When any substance is melted, you know it becomes liquid, it runs, or flows. We have borrowed our word flux from the Latin word *fluxus,* which expresses the act of flowing. I dare say you have often observed, in ancient maps, the letters *Flu.* printed after the names of rivers; the Latin word for river is *flumen:* a river *flows* along between its banks. Our English word fluid has the same origin; we apply it to liquids, to substances that will *flow,* and spread themselves abroad, unless confined by the resistance of some solid body. The water in this tumbler would *flow* over the table, if it were not confined by the glass.

Several mineral substances that would be very difficult, perhaps impossible, to melt, if they were exposed alone to the action of fire, can be melted with ease, when they are mixed in due proportion with something else. That *something* which causes an infusible mineral to melt, is called its *flux;* it enables heat to dissolve the dry, hard particles, and cause them to flow.

After this explanation, I think you will find no difficulty in understanding, that when we speak of the *body,* or substance, of any kind of glass, we mean the sand or stones employed in making it; and when we speak of the *flux,* we mean the material that assists in melting the sand, or whatever may be substituted for sand.

This tumbler is a specimen of *flint-glass;* it is called by that name, because the body of such glass was originally made of ground flints. The Venetians also employed a sort of pebble, resembling white marble, which they found in the river Tesino. Such stones make a beautiful, transparent glass, but the preparation of them for use is troublesome and expensive. Sand is now preferred for that purpose; it saves a great deal of trouble to the manufacturer, and is, in fact, rock reduced to powder by the gradual operations of Nature. As the rocks of the ancient earth consisted of different kinds of stone, so the ruins of those rocks appear, at the present day, in various species of sand. For making the best glass, they choose sand which is fine, white, and shining; such sand, when examined through a microscope, appears like small fragments of rock-crystal. The English glass-houses are supplied with it from Lynn, in Norfolk, from Maidstone, in Kent, and from Alum Bay, in the Isle of Wight; it composes the body of our finest glass.

Now, for the flux to melt this sand, our manufacturers are not content with potash, (or salt obtained from the ashes of vegetables,) because glasses made of sand and salt only are too brittle, too easily broken; this defect is remedied by adding to the flux a portion of red-lead: lead you know is a substance which is very heavy, melts easily, and bends easily. The consequence of this addition to the mixture is, that the lead imparts some of its own properties to the glass, which will be more easily melted, heavier, less brittle, and not so white as if it had been made of sand and pearlash only. The purer the substances employed, the more transparent and beautiful the glass will be.

We come now to the glass used for windows.

The best kind is called *crown-glass;* it is made of fine sand and kelp, or the salt obtained from the ashes of sea-weed.* No lead, or other metal, is used as a flux in making it. Crown-glass is therefore much harder than flint-glass, and it would be more difficult to fashion into different shapes; but this is of no consequence, as it is designed especially for windows, which require only a plain surface.

In the first melting, transparent glass is not produced; but a greyish-white, tough mass, which is cut into brick-shaped pieces, and, when cold, piled up for future operations. After being melted a second time, and perhaps adding a portion of common salt to increase the transparency, the glass is fit for blowing.† You may form some idea of this operation, if ever

* Ure, ibid. 506. † Ure, ibid.

you have seen soap bubbles blown by means of a tobacco-pipe. The glass-blower uses an iron tube, by repeatedly dipping it, he takes up from the mass of melted glass, as much as he supposes will be sufficient to form a sheet of glass of the usual size, which generally weighs ten or eleven pounds. He then rolls the lump sticking to the end of his tube, on an iron table, till it is of a roundish form; he now begins to blow, and the lump dilates into the form of a pear; it is then heated again, and a second blowing makes it swell to a still larger size, and rounder form; a third time it is heated and blown, which makes the bubble yet larger and thinner in substance. The side opposite the tube is now flattened by pressure against a table, or other smooth surface, and it is then ready to be disengaged from the tube used in blowing. I will endeavour to explain how this is done.

An assistant takes a solid iron rod, smaller and lighter than the tube used for blowing; he collects a small portion of melted glass on the end of this rod, and applies it to the centre of the flattened side of the glass bubble; there it sticks fast, so that the bubble is held between the tube on one side, and the rod on the other. A small piece of iron, wetted with cold water, is then drawn round that part of the glass which is connected with the tube, and the glass cracks in the circle traced by the cold iron. The workman gives a smart blow to his tube, the circular crack separates at once, and the glass is left attached to the solid iron rod on the flattened side, and having a round hole opposite to it on the other.

Now, then, the glass must be heated again, in order that this flattened globe may be converted into a plain surface, like the top of a round table. If I tell you how this is done, you will think it almost like a conjuring trick; and I believe it does appear unaccountable and surprising to every body who sees it for the first time.

The workman begins to twirl the iron rod in his hand, slowly at first, then faster and faster, as a woman twirls a mop. Every thing that is whirled round and round, has a tendency to fly off from the centre of motion. So it is with the particles of glass in the bubble; they obey the impulse given them; the glass becomes broader and broader, the round hole larger and larger, till at length it suddenly flies quite open, and the glass bubble is changed into a flat, round plate, measuring rather more than four feet across, and of equal thickness, except in the spot where it is attached to the iron rod; there is seen the knot or lump of glass by which the rod was fixed to it, this is called the *bull's-eye;* I have procured one from the glazier, and also a piece of the outer part of a table of glass. As they lie before you, you may easily imagine a wide circular plate of glass extending round this bull's-eye as a centre. The rod, like the blowing-pipe, is disengaged by touching the surrounding glass with a cold, wet iron, and the finished plate is put, resting on its edge, to cool gradually in an oven. Twelve such plates make what glaziers call a crate of glass.*

* Lardner, chap. iv. and v.

When different manufactures are carried on in a country, the materials employed in one art, or the refuse of them, may be used in another, and by this means the article is made at a cheaper rate: thus the soap-maker and the glass-maker both want soda, and the waste or refuse matter that is left after the soap is boiled, when mixed with sand and kelp, produces an inferior glass for windows, which is called *broad-glass.*

The coarsest kind is the common green *bottle-glass.* It is usually made of soap-boilers' waste and river sand, or of common sand and lime, with a little clay, and salt obtained by evaporating sea-water. When the glass is properly prepared, it is blown into the form of bottles, which are afterwards cooled very gradually in an oven.

Besides these blown glasses, there is another kind which is used for looking-glasses, for the windows of carriages, and frequently for the windows of houses and shops. It is called *plate-glass,* and is made of sand, soda, nitre, and quicklime.

Lime is used as the flux, it promotes the melting of the sand and soda.*

It is said, that the idea of casting glass into plates, was suggested by an accident, which happened to a man employed in a glass-house. He was melting some of the material in a crucible, which is a kind of pot or vessel, made to bear the heat of a very strong fire; while engaged in this operation, he either overset the crucible, or spilled a great part of its contents: the melted mass falling on the large flag-stones, with which the place was paved, penetrated the joining of the pavement, and ran under one of the stones; this obliged the workman to take up the stone, in order to recover his glass: to his great surprise he found it lying beneath the stone, in the form of a plate or sheet of glass, such as could not have been produced by the usual method of blowing. He was very much impressed by this fact: it set him to thinking so intently, that when night came he could not sleep. He saw at once that much better looking-glasses

* Ure, ibid. and Lardner, p. 197.

might be made by casting, if he could only contrive a good method of doing it. He resolved to try, and set about his experiments immediately, and with such good success, that before sunrise the next morning, he proved the possibility of making the great improvement which this fortunate accident had so unexpectedly suggested. This circumstance is said to have taken place towards the end of the fifteenth century.*

It was evident that great advantage would result from casting glass at once in the form of plates, especially when required to be very large: a glass bubble can only be *blown* of a certain size, but there seems no limit to the dimensions of a *cast plate,* except the expense of the machinery required to produce it. The process is simple enough; something like that pursued in making sheet-lead.

When the glass is melted, it is poured out upon a table, which should be of metal, perfectly level, and furnished with iron ledges of

* Lardner, ibid. p. 138.

the same thickness as the plate of glass is intended to be: the ledges are to confine the fluid glass to the size proposed. A heavy copper roller then passing over it, pushes the soft glass before it, and presses it into a smooth, level surface. The newly formed plate, when sufficiently hardened by cooling, is slid into a furnace, or kind of oven, where it remains for a fortnight; care being taken that it should cool very gradually.* The plates thus formed are afterwards ground to a more exact level with sand; and then polished with emery, tripoli, and putty, till they acquire that beautiful surface we are accustomed to see.†

I have said, that we are indebted to the ingenuity of the French for the art of casting plates of glass.‡ At Ravenhead, in Lancashire, they are now cast in such perfection as to equal, in every respect, those that are made in France. A number of persons have formed themselves into a company, to defray the great expense and share the profits of the undertaking. They

* Lardner, ib. 203. † Grey s Op. Chem. 561. ‡ Ency. Brit.

have an iron casting-table fifteen feet long, nine feet wide, and six inches thick. This enormous table is so heavy that it is supported on castors, for the convenience of moving it close to the mouth of the ovens, in which the plates of glass are to be gradually cooled.

The room in which this great table stands, is said to be the largest under one roof that has ever been built in England. It is even larger than Westminster Hall, being three hundred and thirty-nine feet long, one hundred and fifty-five feet wide, and proportionably lofty. The melting furnaces are ranged down the middle, and occupy about one-third of the apartment. The *ovens,* in which the glass plates are gradually cooled, are placed in two rows, along the side-walls of the room. Each of them is sixteen feet wide and forty feet deep. Their floors are just level with the top of the great casting-table; so that when all is ready, the table may be rolled up to the mouth of the oven, and the plate slipped in without delay.

It is a great favour to obtain admission to a plate-glass manufactory. Mr. Parkes, who was permitted to witness the casting of a large plate, describes it as a grand and interesting sight. A vast body of melted glass, of the finest and purest materials, is poured at once from an immense crucible; when the large copper roller has passed over it, the glass is spread out into a sheet of uniform breadth and thickness, and its surface exhibits a variety of colours. At least twenty workmen are employed in the operation. All are busy; but there must be no bustle—no disturbance of any kind: even the opening or shutting of a door must be avoided, till the glass is tolerably hardened, lest the motion of the air should cause a wave or wrinkle on the surface, and thus lessen the value of the plate.*

We will, if you please, leave our plate to cool in the oven, as it is quite time that I should relieve your attention. It would be a pity, in seeking to amuse you, to make you feel like the Esquimaux who were taken to see London. When they returned home, they sat down with

* Lardner, 196, 203.

their elbows on their knees, and hid their faces between their hands: they seemed quite melancholy and stupified. They would answer no questions: they would say nothing but, "Too much smoke—too much noise—too much houses—too much men—too much every thing."*

If you wish to hear any more respecting glass, I shall be happy to see you another evening. We will now take warning by the Esquimaux, and leave off before you have had *"too much."*

* Edgeworth's Practical Education, Vol. I. p. 118.

LECTURE II.

MANUFACTURE OF GLASS CONTINUED.

ARTICLES LAID ON THE TABLE.

RUPERT'S DROPS.
FLINT-GLASS; PLATE-GLASS; MANGANESE.
LOOKING-GLASS; TIN-FOIL; QUICKSILVER.
GLASS BASKET; DOG AND SHIP.
THERMOMETER.
GLASS BEADS.
FRAGMENTS OF TESSELLATED PAVEMENT.
POCKET MAGNIFYING GLASS.
SPECIMENS OF ROMAN MOSAICS.
DITTO, OF ANCIENT GLASS FROM HERCULANEUM.
PLASTER-CAST OF THE PORTLAND VASE.
DRAWINGS FROM DITTO.
ROMAN CAMEO.

LECTURE II.

MANUFACTURE OF GLASS CONTINUED.

After the last Lecture, one of the company remarked, that "It seemed very strange to put any thing into an oven *to cool it!*" Perhaps others have had the same thought; I will therefore begin by explaining the nature of this process, and the advantages resulting from it.

I might tell you, in a very few words, that it was intended to make the glass less brittle, less liable to be broken; but I hope such an answer would not satisfy any of you; and if I endeavour to give you a better, I must first confess my ignorance:—I cannot tell you the *cause of brittleness* in any substance. But though it is not known why some substances are more liable to break from slight causes than others, experience teaches us that many bodies which may be melted by heat, are rendered hard and brittle by sudden cooling. This is particularly the case with glass; but the inconvenience is avoided by cooling it very gradually and equally through its whole substance.* If glass were allowed to grow cool in the open air, the outside would cool first, and it would be liable to break with the slightest scratch or touch. Some people think the reason of this is, that the outer particles, which form the surface of the glass, contract in cooling, while the inner substance remains soft and expanded; and that, in consequence, such glass can never be of one uniform texture.

Before we go any farther, it may be as well to inform you, that the process of gradual cooling to which glass is subjected is called *annealing:* a term derived, I believe, from the Saxon—the language that was spoken in England before the Norman conquest. To anneal is to *temper,*

* Ure, ib. 167.

to bring to a proper hardness by *very* gradual cooling. Every kind of glass of which I have hitherto spoken is annealed; and though, as you very well know, it requires care in using, it is sufficiently strong for common purposes.

The annealing-oven is a long, low chamber, heated at one end, and when intended to receive bottles, glasses, or other small articles, it is furnished with many shallow iron trays, which can be slipped easily along the level bottom of the oven. Each tray, as it is filled, is pushed forward to make room for another, till at length they reach in succession the cool end of the oven, from which, when the glasses are taken, they are found to be almost as cool as the air of the room.

The trays are called *lier*-pans or *fraiches*: words derived from the French, and expressive of the process—*lier,* to unite; and *fráiche,* to cool. To anneal is to unite the particles of a body more firmly, to harden by cooling.

I will now tell you some curious facts relating to glass, which, from not having been subjected to the process I have just described, is said to be *unannealed.* One specimen of this kind is called the Bologna phial. It is shaped like common phials, and may be made of any kind of glass; but the bottom of it must be a great deal thicker than the upper part, and when made it must be cooled suddenly in the air. Some of these phials have been struck by a wooden mallet, with force sufficient to drive a nail into most kinds of wood, and the glass remained uninjured; yet they broke readily when a small sharp piece of flint, weighing only two grains, was dropped gently into them: even a grain of sand has produced this effect, causing the thick bottom of the phial to crack all round and drop off. When the falling substance has been *very* hard and sharp—a cut diamond, for instance—it has been seen to pass *through* the thick bottom of the glass, apparently meeting with as little resistance as would be offered by a cobweb.

This seems a marvellous story, but there is no disputing well-authenticated facts. There are various explanations of the phenomenon. Some ascribe it to a different arrangement of the particles of glass, in consequence of its hasty cooling; others, to its being rendered more electric by that means; but I believe all agree that the disproportioned thickness of the bottom is an indispensable circumstance in the experiment; and that the thicker it is, the more easily the phial will be broken by the minute and sudden shock it receives.

If I knew where to procure a Bologna phial, I should be glad to show you the experiment. There seemed more probability of obtaining another kind of unannealed glass, called Rupert's drops. After many fruitless inquiries, and some unsuccessful attempts to make such drops myself, I was on the point of giving it up altogether, when a shopkeeper very obligingly sent me the real thing, which I have now the pleasure of showing you.

These drops are small, solid pieces of common green glass, which have been suffered to fall, while red-hot, into cold water, where they took the form you see, that of roundish lumps, lengthening into a sort of tail. The thick, round part will bear a hard blow; but if one of you will grasp it in your hand, while I break off only the tip of the tail, the whole drop will burst into minute fragments. I have heard, that if one of these drops is put into a phial or tall glass filled with water, and the end of it is broken off with a pair of pincers, the bulb will fly in pieces with such force as to break the vessel in which it is contained.* It is said, that the stoutest wine or beer bottle would not be strong enough to withstand the shock. We will not attempt this experiment, as I am afraid some particles of glass may be thrown amongst you. You may believe the fact, if you please, on the authority of Dr. Lardner. But if any of you will hold a Rupert's drop firmly in your closed hand, while I break off the tip of the tail, you may do it very safely; and observe how completely the particles of glass will be separated by that slight shock.

* Lardner, 173, 175.

It would be useless to enumerate all the ingredients employed by glass-makers, because you would not recollect the names of them. If you compare these two specimens, the one of flint-glass, and the other of plate-glass, you will perceive an evident difference in their colour. Place the edges of the two pieces side by side, and you may observe it distinctly: the plate-glass is considerably darker than the other. This is produced by the addition of a metal called manganese, which also increases the reflecting power of the glass: this is an advantage, as plate-glass is generally used for looking-glasses.*

When you are passing along the street, you may observe a shop which has windows of plate-glass, and compare its power of reflecting objects with that of common crown-glass in the windows of the next shop. You will at once perceive that there is a great difference between them. But to make plate-glass completely answer the purpose of a mirror, we must call in

* Ibid, and Gray's Op. Chem. 559

the assistance of metals, which are applied in so simple a way that I think you can easily understand it. Here is the effect you see, in the silvery appearance on the back of this piece of glass. I will tell you how it is produced.

A smooth, thick slab of wood or stone, inclosed in a wooden frame, is placed on a pivot, so that either end may be raised or lowered at pleasure. When it is used, the slab must be placed in a level position, and covered with paper. A sheet of very thin tin-foil is then laid upon the paper; and as much quicksilver is steadily poured over it as will remain on its flat surface. Now comes the difficulty—the nicety of the operation, which consists in sliding the plate of glass to be silvered so dexterously into the frame, that it may just dip into the surface of the quicksilver as it glides along, without once touching the tin-foil that lies beneath it, When this is happily accomplished, the plate is suffered to drop gently down by its own weight. Some of the quicksilver is thus squeezed out from between the glass and the tin-foil, but more is left than is wanted: the plate is therefore covered with thick flannel, and loaded with weights placed at regular distances. The whole is then, by means of the pivot, placed in a slanting position, that the superfluous quicksilver may the more readily escape. In the meantime the tin-foil and part of the quicksilver become incorporated; that is, mixed together into one substance, which is soft at first, but soon hardens, and adheres firmly, as you see in this specimen, to the surface of the glass.* It then reflects accurately any object placed before it, and becomes what we call *a mirror,* or looking-glass.

Let us now consider some of the purposes to which glass is applied.

Many of these, being quite familiar to us from daily use, I am afraid we are not so sensible as we should be of the great benefit we derive from glass. For instance, we have never experienced the inconveniences that must have been felt before the introduction of glass windows: per-

* Lardner, 210

haps we have not thought about the matter; and you may be amused by the simplicity with which an old writer alludes to them, while giving an account of some ecclesiastic who had obtained glass from abroad, probably from Venice, for the windows of the church of his monastery. "And thus," says the chronicler, "he kept out the birds and the rain, and did not exclude the light." Marvellous, indeed, must have seemed the luxury till then unknown; and for a long time it remained confined to churches and palaces: five hundred years passed away, after the introduction of window-glass into England, before it was commonly seen in private houses. I think the general use of it is dated in the latter years of the reign of Henry Plantagenet.

While the Tudor and Stuart princes filled the English throne, drinking-glasses were precious utensils, and our country was supplied with them from Venice. The art of making them was not perfected amongst us till the reign of William the Third; and very long afterwards they were not used in the profusion they are at present. Persons now living can recollect the time when large silver cups, or tankards, used to be handed round at dinner-time; and one or two such drinking vessels were thought sufficient for all the guests. This custom has been quite abolished by the general adoption of glass.

I wish I could give you some idea of the quickness and dexterity of the workmen employed in making a common wine-glass. It is formed in three parts, which are all blown, or wrought separately, and then joined together; but I believe no one can form a just notion of the expedition and ingenuity of the workmen without witnessing their operations.*

Many useful and ornamental articles are made of glass, with the aid of a lamp and a blow-pipe. There are persons who travel from place to place, and take up their abode for a few weeks, wherever they meet with encouragement. They set up their table, arrange

* Ency. Brit.

their lamp, bellows, and a few very simple tools, with which, from pieces of different coloured glass, they make a great variety of toys and ornaments. Directing the flame of the lamp upon the glass with a blow-pipe, they pull, and twirl, and divide, and join, till, from a shapeless lump, they produce an elegant little basket or dog, with such apparent ease and dexterity, that you would be as much astonished as pleased, if you had an opportunity of witnessing the process. I have stood by and watched the formation of little dogs and baskets; but have never witnessed, what seems to me the triumph of this sort of glass-working—the making of a ship, with all its masts and rigging complete, like the beautiful specimen we now have on the table. Is it not astonishing that a substance we are accustomed to think so brittle, can, by judicious melting and cooling, be rendered so ductile as to admit of being drawn out into the slender threads which imitate, as you see, the various parts of the rigging; and more astonishing still, that these mimic ropes should have strength sufficient to retain their shape and situation!

The tubes of thermometers and barometers are also made by means of the lamp and blow-pipe. This is done by drawing out quickly, and while the material is soft with heat, a thick, short tube, into one that is thin and long. Two workmen are required for this operation: one collects a lump of glass upon the end of his pipe, and *blows*, till the tube is sufficiently lengthened: the other then takes a solid rod, and fixes it to the opposite end of the newly-formed tube. Now they walk backwards, receding farther and farther from one another, and drawing out the soft, ductile glass, till it becomes a tube as long and as thin as they wish it to be. It is then laid gently down on a frame, in shape something like a ladder, which is placed upon the ground ready to receive it. The tube presently cools, and may then be cut into suitable lengths.*

It is something in this way that an article is

* Lardner, 226.

made with which all of you are familiar: I mean glass beads. Who does not employ them to ornament the endless variety of purses, watch-strings, and pincushions, which engage so many busy fingers during the long winter evenings?

You go to a shop and purchase beads of red, green, blue, white, of almost any colour you please. These various tints are given by mixing with the glass, while it is perfectly fluid, a substance capable of imparting the hue that is required. Charcoal, made from the wood of the beech-tree, affords a gradation of shades, varying from a brown to a clear yellow. Copper will give that beautiful carmine red with which, in your bead-work, you imitate the petals of roses; add a little iron, and you will have a deeper shade of red, to represent the darker tints of the flower. Glass may be coloured blue by a preparation of cobalt; and yellow, by antimony; and if it is desired to have green glass, it may be obtained by mixing these blue and yellow glasses in fit proportions, and melting them again.* I dare say you have often made green paint, by mixing Prussian blue and gamboge on your pallets; and the principle is the same: green is a compound of blue and yellow.

But though you have frequent occasion to buy beads, did it never occur to you that the wants of many little girls must be supplied by the labour of a proportionate number of men? There is a considerable manufactory in Murano, one of the Venetian islands, devoted to the formation of glass beads, or rather to the formation of the tubes which are afterwards made into beads.

The tubes, or pipes, are made much in the same way as those intended for thermometers, only that the movements of the workmen are described as more expeditious. The glass-house contains a room, or gallery, one hundred and fifty feet long: it is something like a rope-walk; and there the men are seen holding the glass pipes between them, and running away in opposite directions. Sometimes they make

* Lardner, 274, 279.

striped tubes, by taking lumps of glass, of different colours, and twisting them together, before they are drawn out into the required length.

The tubes, when properly cooled, and cut into convenient lengths, are packed in chests, and sent to Venice, where they are made into beads, such as you are in the habit of using.

It requires a good deal of practice to cut, or chip, these slender pipes into such minute portions, and to make them of one uniform size. I believe this quite depends on the skill of the workman; and when he has completed his task, these morsels of pipe are only rough fragments. You would find it very unpleasant to use them, on account of their sharp, ragged edges; and I am afraid you will hardly invent a method of curing this defect. It would be very tedious to file or grind all the rough edges: so tedious, that the price of labour would make the beads too expensive for you to purchase them. It was therefore necessary to contrive a method of smoothing a great many beads at once, by the same operation. The end is attained in this way: the tiny fragments of glass-pipe are thrown into a bowl, containing a mixture of sand and wood-ashes; in this they are continually stirred about, until the small hole in the middle of each little piece is filled with sand and ashes. The bowl is then emptied into a vessel made of metal, and furnished with a long handle: more ashes and sand are added, and the pan is set over a charcoal fire, till the beads become hot; and during all this time they are kept stirred continually.

This is a very simple method of making the beads smooth, and rounding their sharp edges, but it answers completely. As they soften by the heat, and are kept rubbing against each other, all the rough edges are worn away, and they gradually assume that globular form, which you know beads possess. When they are thus brought to a proper shape, they are suffered to cool, and are then well shaken in sieves, in order to free them from the sand and ashes with which they were filled. Perhaps you may wonder why the holes were filled up at all; but if you think for a moment, you will perceive that when the beads became softened by heat, they would not have remained hollow, the sides would have fallen in, and then they would not have afforded a passage for your needles.

When the sand has been shaken out of the hollows, the beads are put into other sieves of different degrees of fineness, that they may be separated according to their sizes. The finest sieve allows only the smallest size of beads to pass through it: those that are a little larger, are run through a somewhat coarser sieve, and so on, till all are sorted. They are then strung upon separate threads, by children, made up into bundles, and packed in casks to be exported to foreign countries.* See how much labour and ingenuity are requisite even to make a thing so insignificant as a glass bead.

Ingenuity and patience have been remarkably exercised in another kind of glass-work, called Roman Mosaic. Mosaics are representations

* Lardner, 234, &c.

of objects, or various patterns and figures, composed by joining pieces of stone, glass, shells, or other suitable substances, very neatly, so as to form one smooth surface. In ancient times, the floors of apartments were often paved in Mosaic; and I think you must all have heard of the Roman pavement at Bignor, which is of this kind, and has often been visited by the curious. The patterns are formed by the nice arrangement of different coloured pieces. Our modern floor-cloths appear to be painted in imitation of Mosaic pavement; the pattern is formed by coloured spots. The Romans, however, did not always employ stones of different colours in their pavements. The remains which were some years since discovered at Fishbourne, were all, I believe, like these specimens. They are a rude kind of Mosaic, formed, you see, of separate pieces, joined by a strong cement. Such pavements are called "*tessellated*," from a Latin word, which means variegated by squares; but they are, in fact, a very coarse kind of Mosaic. These separate pieces may represent the pins of glass, which are so minute in the delicate works I am going to show you, that perhaps you will hardly think it possible they can be put together in the same manner.

Here is a miniature representation of the castle of St. Angelo, and also the triumphal arches of Severus and Constantine, relics of the grandeur of ancient Rome. You would, at first sight, think they were paintings, and perhaps by candle-light you may not be able to distinguish any thing like the joining of distinct substances; but I assure you that the materials used in composing these little pictures, are pieces of glass, of every shade and colour that the subject requires. The glass is first cast into thin cakes, which are afterwards cut into long pieces. This mode of forming pictures was, about the beginning of the last century, employed on a larger scale, in decorating some of the churches in Rome. The original paintings being in a perishing state, from the dampness of the walls, this method was adopted of supplying the place of the old pictures, with copies made of a substance that would not be spoiled by damp.

When the glass picture was intended to be looked at from a distance, the pieces used were large in proportion; but in fine works, or ornaments like this, where the objects represented are small, and designed for close inspection, the artists employed pieces of glass no thicker than a common needle or small pin; so that a picture of four feet square, would take two millions of these glass pins to complete it. It is a very tedious operation to make such pictures, and requires a great deal of method, as well as patience and ingenuity.

In the first place, the glass pins must be carefully sorted, according to their shades and colours, and laid ready before the artist, in a case, or frame, divided into compartments, as the letters are sorted and laid before a compositor in a printing-office. A paste made of calcined marble, fine sand, gum, white of eggs, and oil, must then be spread, as a ground to receive the glass pins. The paste should be so soft, that the pins may easily be put in, and, if necessary from any mistake, taken out again, and their position changed. When all is thus prepared, persons skilful in the art, will imitate the finest strokes of a painter so accurately that the glass picture can be distinguished from the original only by its lustre, and the greater brightness of the colours.*

The ancients were in possession of a still more delicate and curious method of forming pictures, by joining filaments, or threads of various coloured glass. Many specimens are preserved in the British Museum, but the art of producing such pictures is now lost. We only know that it once existed by the specimens which have been accidentally discovered. They are mostly in small pieces, like those composing this elegant bracelet, which were found in the ruins of Herculaneum. You will perceive that the various pieces constituting each plate, are so accurately united, that I believe, even with the help of a magnifying-glass, you will be unable to

* Lardner, 285.

discover any thing like a join. No particular object seems to be designed on these plates; but I have read of one specimen, not quite an inch long, and one-third of an inch broad, on which a duck, in colours as lively as those of a Chinese painting, was represented with a delicacy equal to that of the most highly finished miniature. The pupil of the eye, the feathers on the breast and wings, all were there; and to complete the wonder, on turning the glass, the bird appeared as perfect on the reverse side! This circumstance led to the conclusion, that such pictures must have been formed by joining slender threads of glass, in the way I have mentioned, and afterwards subjecting them to heat, so powerful as almost to melt them into one compact body; but *how* they managed to effect this remains a secret.*

The most celebrated specimen of ancient glass is a vase, or urn, of exquisite workmanship, from which the plaster cast on the table is modelled. The original was found, about the middle of the sixteenth century, inclosed in a

* Lardner, 283.

marble sarcophagus, which was deposited in the tomb of the Roman emperor, Alexander Severus. You must not confound the name of this prince with that of another Roman emperor, also called Severus, a man of very different character, a stern, ambitious, veteran soldier, who was raised to empire by the Pannonian army under his command. His name was Septimius Severus: he came into Britain, which was then a Roman province, in order to quell a revolt; and he built, or, according to some, repaired and strengthened by new fortifications, a wall previously erected by Adrian, between the rivers Forth and Clyde, to restrain the incursions of the Caledonians. After this he died at York; and some hills in the neighbourhood of that city are still known by the name of Severus's hills. Some of you have probably heard of, or read, the Poems of Ossian; and you may associate the name of Septimius Severus with that of Fingal, the father of Ossian, and the chief of his heroes, who commanded the Caledonians at that period. Fingal is said to have eluded the power of Severus, and to have gained a complete victory over his son Caracalla, which is celebrated in one of the poems of the Scottish bard.*

It was about twelve years after the death of Septimius, that Alexander Severus, at the age of seventeen, succeeded his cousin Heliogabulus in the government of the Roman empire. The character of this young prince appears more amiable, from the striking contrast it presents to the sensual, dissolute tyrants who reigned before and after him. He was blessed with an excellent understanding, and a good education, and soon perceived the advantages of virtue, the pleasures of knowledge, and the necessity for cultivating habits of industry. He rose early, gave his first thoughts to religion, and then devoted himself to the duties of his high station. Bodily exercises, elegant literature, and the conversation of men of learning and virtue, filled up the remainder of the day. Plain and modest in his dress, courteous and affable in his manners, he merited and enjoyed the love and gra-

* Gibbon, i. 181—209. Tytler's Chron. Tab. Hume, i. 10

titude of his subjects, who were freely admitted to his palace at proper hours, under one restriction: an officer was appointed to proclaim in a loud voice, "Let none enter these holy walls, unless he is conscious of a pure and innocent mind."*

These words were borrowed from the Eleusinian Mysteries, a religious festival of the ancient Athenians, in which the same admonition was publicly repeated. The figures which adorn the urn that was so carefully deposited in the tomb of this youthful emperor, are believed to be allegorical, and to have a reference to those mysteries. Alexander Severus could not have been wholly ignorant of Christianity, since its doctrines were openly professed, and its worship practised by some of his household; but he seems to have been, like many of the ancient Romans, more inclined partially to adopt a new religion, than to relinquish the old one. Hence the temple consecrated to his private devotions, was ornamented with the statues of Abraham,

* Gibbon, i. 224—246.

of Orpheus, of Apollonius, and of Christ, all of whom he honoured, as persons who had instructed mankind in different modes of worship.*

A certain degree of truth always appears to have been blended with ancient fables, and also with the religious opinions of the best and wisest men among the heathens; particularly some obscure, imperfect notion, that man is to live again after death. This great truth was possibly handed down, by tradition, from the first patriarchs, and became gradually mingled with many errors and superstitions. The Eleusinian Mysteries are said to have been designed to teach this doctrine, by a succession of scenic representations, so contrived as to impress the minds of those who witnessed them with awe and terror. There are two striking points of contrast between false and true religion. First, Paganism was the religion of fear.—Christianity is the religion of gratitude and love. Second, the truths preserved by tradition, and taught among the ancient heathens, were imparted only

* Gibbon, vol. ii. 441.

to a favoured *few;* and carefully guarded from all but the initiated:—the truths revealed by Christianity, are "glad tidings for *all* people;" and every one who will receive them, may freely partake of the glorious hopes and unspeakable consolations they impart. The most careless observer may perceive these opposite characteristics of Heathenism and Christianity.

Persons who desired to be admitted to the Eleusinian Mysteries were obliged to purify themselves by bathing in the river Ilissus, and offering up certain prayers and sacrifices. When the ceremony of initiation was performed, they were admitted into the temple during the night. The solemnity of darkness and silence, the knowledge that they were about to see and to hear things which the laws of Athens forbad them to reveal, under penalty of death, must have excited the imagination, and rendered the judgment less capable of detecting the various artifices by which the priests imposed upon the senses.

Suppose a young Athenian, educated in the superstitions of his country, ignorant of the true character and the providential government of God, brought by night into the temple of Ceres, to be instructed in mysteries which were then deemed sacred as well as terrible—fear and awe must have taken entire possession of his mind. All at once the darkness was dispelled by a sudden blaze of light; swift and momentary as a flash of lightning—it vanished, and left him again in darkness, which seemed more profound from the contrast. Long, rolling peals of thunder then shook the walls of the temple, while the ground beneath his feet seemed to heave as if agitated by an earthquake. Strange voices were heard, and spectral illusions (which doubtless were a kind of phantasmagoria, emblematically representing the doctrines to be taught) were presented to his astonished sight. The young Athenian must have had very firm nerves, if he could witness all this without feeling too much bewildered and terrified to listen to what was read to him from the mysterious volumes that were preserved in the temple.*

Rollin's Hist. Anc. v. 13, 14.

Part of the scenic exhibition is supposed to be sculptured on the sides of this urn.

The representation of Death was one of the first scenes in the Mysteries. The central figure in this group appears to be emblematical of *Mortal Life:** she holds in her hand an inverted torch, which is an emblem of death. You know that if we were to hold a lighted candle in that position, it would go out almost immediately. The attitude of the figure expresses great lassitude and weakness. She seems vainly endeavouring to support her drooping head with her hand; but it is plain that she is sinking down; Mortal Life is expiring. The side figures of the group are a man and woman, the emblematic representatives of the human race; they both seem to be looking intently at the dying person, but they make no effort to assist her. When death approaches, human help is unavailing.

The perishable nature of the works of art is also represented by the disjointed stones on

* See Frontispiece.

"Immortal Life, her hand extending, courts
The lingering form"—

which these figures are seated, and by the broken column. In the original, the capital of the column is seen lying beneath the feet of Mortal Life :—in this plaster-cast, the capital has been carelessly omitted, which lessens the beauty and justness of the allegory. Here is a drawing, which I believe to be a correct copy, where the broken capital is shown.

Let us now turn the other side of the vase, and examine the representation of *the life after death*. The ancient heathens supposed that the habitation of the spirits of the dead was beneath the surface of the earth. This was the dominion of Pluto, the dispenser of rewards and punishments. The first figure in the group is the shade or ghost of a deceased person, who seems to be advancing timidly through an open portal; his attitude shows that he is stepping *down* from above. He seems to linger, as if afraid, and wishes to drag after him a part of his mortal garment.

Here, I am sorry to say, is another proof of careless execution in the cast. In the original, and in this drawing, the garment is seen clinging to the side of the portal through which the ghost has passed. Man parts reluctantly from his mortal body, and leaves it in the grave—the dark portal through which he must pass to the eternal world.

You see the ghost is received and supported by a female figure, the emblem of *Immortal Life*. As the inverted torch is the emblem of death, so the serpent is the emblem of immortality. I believe this originated from the circumstance of the serpent casting its skin every year, which was thought, by the ancients, to be a fit emblem of renewed youth.

The other figure represents Pluto, the god of the infernal regions: he is distinguished by having one foot buried in the earth, to denote the subterraneous situation of his dominions. The position of Immortal Life shows that she is intending to lead the ghost to Pluto.

The winged boy is the representation of

Divine Love: he flies before the descending spirit, lights him with his torch, and looks back, as if inviting or encouraging him to proceed.

I have not noticed the trees which ornament both sides of the urn; the first may be an elm, which Virgil mentions as shading the entrance of the infernal regions. Those in the second compartment are probably intended to give an idea of the groves of Elysium, the abode of departed spirits.

There is still another emblem which you have not seen. Lift up the vase, and you will find, on the bottom of it, a veiled figure, supposed to represent the priestess of Ceres, in whose temple the Eleusinian Mysteries were celebrated. She is about to put her finger on her lips, as if to enforce the injunction of secrecy, which was imposed on all who witnessed those mysteries.*

The urn from which this plaster-cast is copied, was purchased by the duke of Portland from

* Rollin, ib. Darwin's Botanic Garden, note xxii.

its Italian possessor, for one thousand guineas. Hence it is usually, in this country, called the Portland Vase.

As it is quite impossible for you to form any conception of its delicate workmanship from so rude an imitation, I wish you to examine this Roman cameo, in which white, opaque figures are raised on a dark ground. They appear to have been wrought in the same manner as the sculpture on the Portland Vase, by cutting away the opaque white surface, leaving only so much of it as was necessary to form the desired figures. From this cameo you may obtain a very good idea of the extreme delicacy and beauty of that specimen of ancient art, which was inclosed in the tomb of Alexander Severus. The body of the vase is made of a dark-blue glass; the figures appear to have been exquisitely cut in a white, opaque glass, which seems to have incrusted the lower part of the vase. All this being removed, except where needed for the design, the emblematic figures appear in relief; that is, raised upon the dark-blue ground.

A work of this kind must have required the labour of many years:—the artist, and the date of his performance are both alike unknown; and the mysteries he so elegantly represented, have lost their terrors since the true doctrine of immortal life has been revealed in the Gospel.

I could say much to you on the *transparency* of glass, which has, in a variety of ways, contributed to the extension of our knowledge and happiness; but it is too late to enter on the subject this evening: I will therefore conclude with Dr. Darwin's poetical description of the "mystic urn" we have just examined.

> *Here,* by fallen columns and disjoined arcades,
> On mouldering stones, beneath deciduous shades,
> Sit HUMAN KIND in hieroglyphic state,
> Serious, and pondering on their changeful fate;
> While, with inverted torch and swimming eyes,
> Sinks the fair shade of MORTAL LIFE, and dies:
> *There* the pale GHOST thro' death's wide portal bends,
> His timid feet the dusky steep descends—
> With smiles assuasive LOVE DIVINE invites,
> Guides on broad wing, with torch uplifted lights;
> IMMORTAL LIFE, her hand extending, courts
> The lingering form, his tottering steps supports;
> Leads on to Pluto's realms the dreary way,
> And gives him, trembling, to Elysian day.

Beneath, in sacred robes the PRIESTESS dressed,
The coif close hooded, and the fluttering vest,
With pointing finger guides the initiate youth,
Unweaves the many-coloured veil of truth,
Drives the profane from Mysteries' bolted door,
And silence guards the Eleusinian lore.

LECTURE III.

REFRACTION.—LENSES AND MIRRORS.

ARTICLES LAID ON THE TABLE.

A GLASS PRISM.

RULER, OR STRAIGHT STICK.

BASIN OF WATER.

ROUND DECANTER, OR GLASS GLOBE, WITH WATER.

PLAIN, CONVEX, AND CONCAVE MIRRORS.

DECANTER, WITH COLOURED LIQUID, WELL CORKED.

LECTURE III.

REFRACTION.—LENSES AND MIRRORS.

The variety of useful and ornamental purposes to which glass is applied is so great, that we must this evening confine ourselves to those which are connected with its transparency, and to the effects of certain changes in the direction of the rays of light, which are produced by their passage *through* pieces of glass of different forms, or by being reflected *from* them.

No doubt you all perceive the convenience set forth by the old chronicler, of "keeping out the birds and the rain, without excluding the light:"—of having our houses warm, dry, and cheerful; and, when we travel in a carriage, of being able to enjoy the scenery through which we are passing, in defiance of the weather. And yet these advantages are but a small part of our obligation to the transparency of glass. That property has done wonders in promoting the extension of knowledge—wonders far beyond my ability to explain, or yours to comprehend. Shall I try to give you a faint notion of some of them?

I dare say, that in showery weather, you have frequently, when the sun has been hidden by a small, dark cloud, admired its bright rays issuing, as from behind a skreen, and streaming over other clouds in long lines of light. Well, such rays are always proceeding from the sun in straight lines, and spreading in all directions through the air. In the broad light of day we do not usually perceive these rays, we see only the general effect of them in the brightness of every object on which they fall; but if we close the shutters, so as to darken the room, and then make a small hole in the shutter, a ray of light will be seen streaming across the darkness. By means of a bar of glass like this, which is called *a prism,* I could show you that the ray, which, when we look at it with our unassisted eyes, appears of one white colour, is in reality composed of all the colours of the rainbow. When light passes through a piece of glass of this shape, it is separated into those distinct colours; and, if we hold a sheet of white paper at a proper distance behind the prism, we shall see the colours of the rainbow, in their natural order, reflected upon it. It is to this beautiful experiment that Dr. Darwin alludes, when he says,

> "Cling round the aerial bow with prisms bright,
> And, pleased, *untwist* the sevenfold threads of light."

Here, you perceive that he compares a ray of light to a thread of seven colours twined together; and it is a very just comparison. But perhaps we might never have known it to be just—never have discovered that the greenness of the grass and trees, and the beautiful colours of the flowers in the garden, are not in the grass and flowers themselves, but that the colours we admire are properties of the light which falls upon those objects, and is reflected from them.

We might never have known this, if Newton, or some other ingenious person, had not thought of making experiments with glass prisms.

I said that rays of light issuing from the sun proceed through the air in straight lines. If they meet with a transparent substance, such as glass, or water, the rays still pass onwards, but not in a straight line. The ray that passes through a prism is bent upwards, not in one line of light, but spreading into rays of different colours.

Suppose, now, that we receive those rays, or cause them to fall, upon a sheet of paper held behind the prism, we shall find them arranged in the following order:—the *red* ray, which is the least capable of being turned aside from a straight course, will appear in the *lowest* place on the paper:—the *yellow* ray will bend more; therefore, *higher up* on the paper we should find a spot of yellow light. *Orange* is a compound of red and yellow: its place is accordingly *between* those colours. The blended rays of red and yellow make orange; just as if you grind lake and gamboge on a pallet, and mix them with your brush. A little higher on the paper you will find *blue;* and between the blue and the yellow a tint of *green,* which, you probably know, is composed of those two colours. The blue then deepens into the darker tint called *indigo,* which melts off into a violet hue, and mingles with the sky.

This is the order of colours in the rainbow, that grand prism of nature. Its glorious arch exhibits three primary colours, red, yellow, and blue, with intermediate tints composed of their blended rays. This succession of colours is called *prismatic,* because we may produce it by causing a ray of light to pass through a glass prism.

I have made use of a great many words to explain this bending of the rays of light out of their straight course; but it may be expressed by one single word—REFRACTION. I will show you what a very good word it is for the purpose. Here is a flat, ebony ruler, which is perfectly straight, as straight as the rays of light issuing from the sun: I put the end of it, in a slanting direction, into this basin of water, and you see the ruler appears as if broken across, just where it touches the surface of the water. I will tell you the reason of this. Air, water, and glass are all transparent: they all admit light to pass through; but the particles of water and glass are more *dense;* that is, they are closer together than those of air; therefore the rays of light, on entering them, find more resistance, and are immediately turned from their straightforward course. When a line changes its direction gradually, it forms a curve: when it changes suddenly, it forms an angle; and then it appears to be broken, as is the case with this ruler.

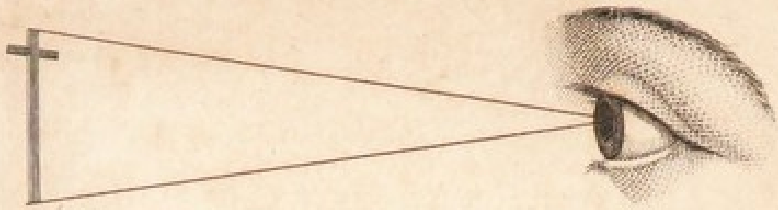
The separation of light into distinct colours, as seen when it has passed through a prism, is also distinguished by another term, referring expressly to that circumstance. It is called DISPERSION. The ray is *refracted;* that is, turned aside from its first direction: it is also *dispersed;* that is, separated into its primary colours.

Refraction is a term borrowed from the Latin: —*frango* means, I break. We have many words expressive of being broken, or liable to be broken, which have the same origin. *Fracture, fragment, frail, fragile,* are all examples of this; and thus, when we speak of a refracted ray of light, we mean a ray that is broken, or turned aside from its former course.

When we are looking at any particular object, it seems to be in a direct line before us; that is, we can fancy a line drawn straight through the air, from the thing we are looking at to our eye; and, in fact, the rays of light reflected from that object do pass straight through the air until they meet our eyes. We are so accustomed to this, that we always imagine the thing we are looking at is in a straight line before us. But, if the object of our attention is in *water,* the ray proceeding from it to us will, on coming out of the water into the air, be refracted, or bent, and that so considerably as to deceive us with regard to the situation of the object. When we are walking beside a clear pond or stream, we may often see a fish swimming along, apparently near the surface. Suppose, now, a boy wishes to shoot that fish with an arrow, he will not succeed unless he directs his aim *beneath* the place where the fish seems to be: it is, in reality, deeper down in the water than the place it appears to occupy.* Let us prove that this is true by an easy experiment.

I will substitute a shilling for the fish, and fix it on the bottom of this basin with a wafer. Now that I have set it on the table, do you step gently back, just far enough to lose sight of the shilling. As soon as the edge of the basin hides it from you, stand still. I now pour water into the basin till it is almost full. There—I believe you all see the shilling distinctly, lifted up, as it were, into your sight by my pouring in the water; but this is a deception, produced by the refraction or bending of the ray of light reflected from the shilling. As soon as that ray leaves the water and enters the air, it bends towards your eye, which, being accustomed to

* Joyce, Sci. Dial. v. 37.



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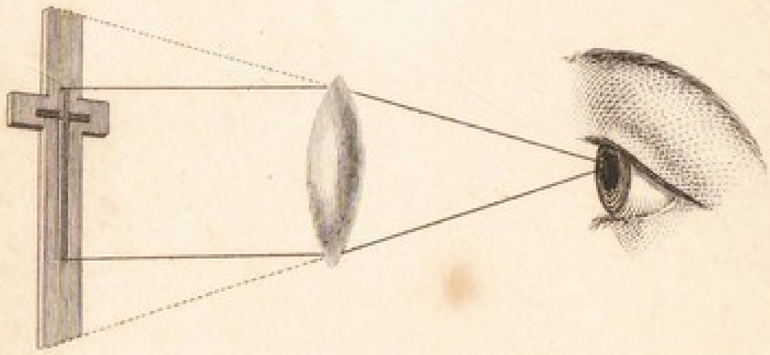

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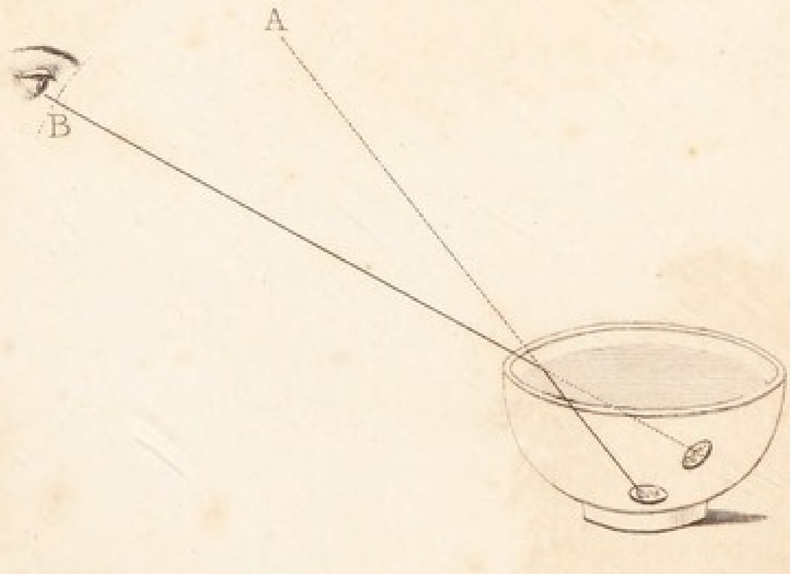

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look right onward, sees the shilling as if it were an inch or two beyond the place where it is fixed to the basin. The wafer has kept its hold; so that we are quite sure that the shilling has not moved. Your eye has been deceived by the power of refraction.

Perhaps this little drawing, in which the rays are represented by lines, will show you more plainly how the deception is produced.

If there were no water in the basin, there would be no refraction. The ray reflected from the shilling would pass right on to A, and a person standing there would see the object; but an eye at B could not see it, because the edge of the basin would be in the way.

Now, suppose water to be poured in, and the ray in consequence reflected to B, the eye there, looking straight on, would see the shilling—not where it really is—but a little higher up, and towards the opposite side of the basin, as represented in the drawing.

Let us once more put the end of the ruler into the water, holding it at the same time in a slanting position. You see that the immersed part appears as if it were bent *upwards,* towards the surface; but I press it firmly against the basin—you see that I do—therefore it is evident that the *bottom of the vessel,* as well as the end of the ruler, appears higher than it is in reality. In like manner, if we stand beside a river or pond, in which the water is so clear that we can see the bottom, it will, from the effect of refraction, appear much nearer to the eye than it is: so that, if the pond were six feet deep, we should suppose it to be only four feet and a half; that is, just one quarter shallower than the real depth.* Many a poor lad has been drowned by venturing into water, which, owing to this deception, was much deeper than he had supposed. But on some occasions the refracting power of water has afforded a useful warning to persons who were aware of the fact, and prompt in taking advantage of it.

You have heard of coral rocks, and how they are built up from the depths of the ocean by

* Ib. p 37.

the united labours of millions of little worms, till they reach the surface of the water. As these rocks rise almost perpendicularly, a ship may strike upon, or against them, before any change of soundings has put the mariner on his guard. Perhaps *change of soundings* is a phrase that some of you do not understand. Every ship requires a certain depth of water to swim in; therefore a man is stationed in the fore-part of the ship to find out the depth, by dropping a line, with a weight attached to it, down to the bottom of the sea. This operation is called *sounding*. On approaching common shores, the water becomes gradually shallower, and the pilot knows he must take care not to run the ship aground. But coral rocks give no warning: rising abruptly, even in the midst of deep water, the mariner may suddenly find himself in a very perilous situation. This accident happened to a ship which was pursuing its voyage in the sea of China, and inadvertently passed through a narrow opening in a reef of coral rocks, which rose beneath the water in the form of a horse-shoe, and surrounded the ship. When the alarm was given, the danger appeared imminent. The unusual transparency of the water afforded a distinct view of the enemy that lurked beneath; while its apparent depth was so lessened by refraction, that, as the waves swelled, the rocks seemed to be almost at the surface of the water; and the anchor, which had been let down on the first intimation of danger, appeared, like the rocks, to be lifted up. To move forward, in any direction, threatened instant destruction. The only resource was to keep the vessel stationary, and send out boats to search, by sounding, for the passage through which they had entered. The narrow opening was by this means discovered; and the ship, safely traversing it a second time, was released from that terrible prison.*

I have said that colour is not a quality of the object that seems to be tinged with it, but a property of the light which falls upon that object. A rose appears red because its petals reflect the

* Arnott's Elements of Physics, ii. p. 184.

red rays: a convolvulus reflects the blue rays. If it were possible for these flowers to grow and to bloom in darkness, the rose would not be red nor the convolvulus blue. A lettuce, when left to grow naturally, is green; but, as you may have observed, when the gardener ties it round with a piece of matting, the *inner* leaves, which compose the heart of the lettuce, continue to grow, but they are pale and colourless—deprived of air and light, they do not acquire the power of reflecting the green rays. Red rays proceed from the rose to our eyes, and we call the rose, red; but the redness is in the light.

You have seen, by the little experiment we have just tried, that our idea of the *form* of an object is influenced by the direction of the rays proceeding from it. That ruler appears bent or broken while the end of it remains in the water; though it is not the ruler that is bent, but the rays of light from which we receive our notion of the shape of the ruler.

This, then, is REFRACTION. I hope, when we have occasion to make use of that word, you will distinctly recollect its meaning.

I will now endeavour to explain another change in the direction of rays of light, which is called REFLECTION. This word also is borrowed from the Latin :—*flecto* means, I bend. Reflected rays are those which, after striking or shining on a substance, are bent or driven back again.

When we see the reflection of ourselves in a looking-glass, the image in the glass is formed by the rays of light which fall upon our faces, and are reflected from our faces to the glass opposite to us. The rays cannot pass onwards, because the coating of tin-foil and quicksilver on the back of the glass prevents it: they are consequently *reflected* back again, from the mirror to our eyes, and, passing through the pupil, they form a corresponding image on part of the internal eye, which is so constructed as to reflect any object placed before it. The mind perceives that image or reflection, and then we say that *we see* the object.

We are greatly indebted to *refraction* for bringing many things, particularly those which are very small, or very distant, into a situation to be viewed more conveniently; but, in every case, *reflection,* that is, the bending back of the rays of light that fall upon the object we are looking at, till they strike upon the reflecting membrane in our own eye, is the immediate cause of that wonderful act which we call *seeing.*

Let us now examine in what way we are indebted to refraction for extending the limits of sight. It is a very curious subject of inquiry—a very striking example of what may be achieved by the art and industry of man. The most ignorant may look around him and see many things; but he who reflects on the nature of light, and perseveringly repeats his experiments, may arrest its rays in their progress through the air; collect and bring them nearer and nearer, till they meet in a point, causing heat so intense as to melt the hardest substances. Or he may disperse those rays, drive them farther asunder, and compel them to form large, distinct images of objects so small as to be imperceptible to the naked eye. By what means do you think he accomplishes these wonders? Could you imagine that it is by the skilful arrangement of pieces of glass, ground into various forms, and nicely polished? They are called *lenses.* A single one is a *lense.*

This word is said to be derived from the resemblance of such pieces of glass to the seed of a lentil, which is a plant of the pea kind, but much smaller. We may, therefore, suppose that the first lenses were small globes, or drops of glass, in which the power of refraction was, in all probability, discovered by accident; and that the word *lens* was afterwards applied to larger glasses, used as refractors, without any reference to their being globular; for some lenses have hollow sides.

It is probable that most of you have had an opportunity of seing gold-fish swimming about in a glass globe. Nobody would think of comparing such a globe to the seed of a lentil; but, when filled with water, it is, in fact, a great lens, possessing the power of refraction in a high degree. When the fish glide past, in some directions, the rays reflected from their bright, red scales, instead of passing evenly on towards our eye, part farther asunder; and the consequence of this is, that the fish are magnified, and appear to us very much larger than they really are.

When lines, or rays, in changing their direction, separate farther from each other, they are said to *diverge:* when they draw closer together, they are said to *converge.* Try to remember this distinction.

As I remarked that fish, in a glass globe, appear to be magnified by the *diverging* of the rays of light reflected from them, you will perhaps be surprised to hear that rays of light, after passing through such a globe, will *converge,* draw closer and closer, and at length meet in a point at such a distance behind the glass, as is equal to half of its diameter, or breadth.*

You may convince yourselves, before we pro-

* Joyce, ib. p. 51.

ceed any farther, that both these assertions are correct. Here is a glass globe, containing some minnows: they are not so pretty as gold-fish, but will answer our present purpose. You perceive, at once, how greatly they are magnified, when you look at them through the round part of the glass; and you may see that it is the *roundness*, the lens-like form, which is the cause of their appearing larger; for if you look at the fish through the top of the glass, where the surface of the water is flat, they will seem to be nearly of their natural size.

We may farther illustrate this by an easy experiment, which will also show you that deceptive effect of refraction which I mentioned, as alarming the sailors who were surrounded by coral rocks. I put a shilling into this tumbler, which you see is about three-parts full of water: then cover it with a plate, and turn it over quickly. We have succeeded without spilling the water; and here is a very curious deception. There seems to be half-a-crown lying on the plate, and a shilling swimming above it in the water! The deception is produced by seeing the same piece of money in two directions at once. Looking at it through the round side of the tumbler, it is magnified to the size of half-a-crown; and looking through the flat surface at the top of the water, it appears, like the coral rocks, to be raised up, and seems as if swimming considerably above the plate, where we know, from its weight, that it must all the time be lying.*

Now look straight down through the bottom of the tumbler, which, you perceive, is not perfectly flat, but slightly hollow. The shilling and the half-crown have both vanished; and instead of them you see only one small piece of money, less than a sixpence, and apparently at a much greater distance than the real depth of the tumbler. All these deceptions and changes are caused by refraction.

We will now put out all the candles except one, and place it so that the rays proceeding from it shall pass through the glass globe,

* Joyce, ib. 39—41.

which, being filled with water, has the effect of a great round lens. That small, bright spot of light on the wall behind it, is caused by the rays which have passed through the globe *converging;* that is, drawing nearer and nearer together, till they meet in that bright spot. With a little care in adjusting the places of the candle and the globe, you will see, in the spot where the rays meet, an image of the candle upside-down.

This meeting point is called the *focus* of the lens. *Focus* is a Latin word, which sometimes means the hearth on which a fire burns, and sometimes fire itself. The term is very properly applied to the point where the converging rays meet; for, if such a glass be exposed to the sun, the rays passing through it, and collecting into a point at the focus, will occasion intense heat in that spot. I recollect a circumstance illustrating this fact. Many years ago, I knew a lady who left on her dressing-table an old-fashioned, globular decanter, full of water. The table stood before a window, exposed to the full heat of a noonday sun. On going up stairs again, in the course of the morning, she observed some appearances that surprised her greatly; and as I happened to call on her just then, she asked me to look at them. We went, together, into her chamber: there stood the decanter, as it had been left in the morning; and near it, on the side farthest from the window, the napkin that covered the dressing-table was burned into a hole: the paint on the table beneath was destroyed; and the wood appeared quite black, as if it had been touched by a very hot iron. The decanter of water had, in fact, performed the office of a burning-glass. I have since read of serious accidents resulting from this cause; particularly one in which a house was set on fire, in consequence of a glass, containing gold-fishes, having been left in a sunny window, near the curtains.*

* Arnott's Elements of Physics, ii. p. 205.

Since this Lecture was written, the buildings of a farm near Chichester were destroyed, in consequence of the sun's rays being directed, by the focus of a burning-glass, to the top of an old, decayed post, which ignited, and communicating with the straw in the farm-yard, the buildings were soon in flames.

The great power of this kind of lens was known to the ancients; and glass globes, filled with water, were used as burning-glasses by the Greeks. Aristophanes, the Athenian, in one of his comedies, introduces a person as intending to make a very dishonest use of a glass of this description. He thought it might enable him to get clear of his debts; and said, that when his creditor should come with a writ against him, he would place his glass in the sunshine, at a little distance, and set the writ on fire. Pliny also speaks of glasses that burn by refraction: he calls them balls, or globes, of crystal or glass, which, being exposed to the sun, transmit heat sufficient to set fire to cloth. It has been supposed that the Romans lighted their sacred fire by this means.*

The most celebrated burning-glasses of the ancients, those of Archimedes, are said to have acted, not by refraction, but by reflection. They are supposed to have consisted of small, square mirrors, moveable every way, upon hinges; so

* Hutton's Mat. Dict. i. 231; and ii. 175.

that the sun's rays were converged by them, and reflected with such power upon the ships of the Romans, that they were burned to ashes, though at the distance of a bow-shot. Rollin, in his account of the siege of Syracuse, when relating the ingenious devices by which Archimedes defended that city, rejects the story of the burning-glasses as an idle tale; adding, that no ancient author mentions it: but Dr. Hutton gives the names of eight, who relate it as a fact. The story, if true at all, has probably been exaggerated, especially with regard to the distance of the ships; but what has actually been effected in modern times, may dispose us to give some credit to the exploit of Archimedes.

Buffon, the French naturalist, made a variety of very powerful burning-glasses, employing for the purpose both mirrors and lenses. Among them was one, supposed to be on the same principle as that of Archimedes. It consisted of four hundred mirrors, so placed as to reflect all their rays to one point: with this he could melt lead and tin, at the distance of one hundred and forty feet:

with others, he consumed various substances, at the distance of two hundred and ten feet.*

The power of a burning-glass exceeds the common heat of the sun, as much as the size of the whole lens exceeds that of the circular spot of light formed by the meeting of the rays at the focus. If the size of that spot can be still farther diminished, then the power of the glass will be proportionably increased. Mr. Parker, an ingenious glass manufacturer in London, set to work on this principle. He made a lens of flint-glass that measured three feet across: it was one of the largest that ever had been applied to this purpose. The round spot of light at the focus was just one inch broad. He caused these collected rays to be received by, and to pass through, a much smaller lens, measuring thirteen inches. The spot of light cast by this second lens was diminished more than half: it measured only three-eighths of an inch. Mr. Parker tried a great many experiments with his associated lenses, and soon found that he could

* Hutton, ibid.

perform wonders. This glass had more than seven times the power it had with the larger focus. It melted iron plates in a few seconds: tiles and slates became red-hot in a moment, and were changed into glass: gold became fluid in four minutes; and precious stones in less than half an hour.

I suppose that none of you would wish to put your fingers into the fire, or even to touch the bars of the grate; but Mr. Parker had a strong inclination to try what sort of feeling that intense heat, which he saw melting stones and metals, would produce in flesh and blood. He placed his finger within an inch of the focus; and, finding he could hold it there without inconvenience, he resolved to try the very focus itself. It seems a bold experiment. You will be surprised to hear that his finger was not burned. He experienced no sensation like that produced by the heat of a fire or candle: the pain he felt was more like the prick of a sharp lancet.*

* Joyce, ib. p. 55.

Burning-glasses are of two kinds, *convex* and *concave*. The convex ones are lenses; the rays of light pass *through* them: the concave ones are mirrors; the rays are reflected *from* them.* This is true of burning-glasses; but a lens or a mirror, intended for other purposes, may be either convex or concave. I should like you clearly to understand the difference. You have been accustomed to think of a cave as a hollow place; therefore it will be very easy to recollect that a lens or mirror, having a hollow surface, is called concave. Convex is the opposite to concave; the surface bends outwards. Pass your hands over these two mirrors; and though in each of them the curve is slight, yet it is perceptible. You may feel that the convex mirror rises, and that the concave sinks towards the centre. The eye also is sensible of the difference; so that a person who has made this double examination can hardly forget the distinction between convex and convave.

A common looking-glass has no curve; it is

* Hutton, ib.

flat. Observe the different effects produced by these three forms of surface. The plain mirror on the table reflects objects in their true dimensions; but if you look into it, your right eye will appear to be the left eye of the reflected image; and when you are dressing, the image before you is that of a left-handed person, using the brush or the comb very dexterously. We are, from infancy, so accustomed to this deception, that we do not regard it. We see ourselves reflected in a glass, while we are too young to consider the subject; and when once an appearance has become very familar, we are not apt to think about it. Thus we lose many opportunities of acquiring both knowledge and pleasure.

Let us now take a view of our whole party, sitting, just as we are, round the table. You see we are distinctly reflected in the convex mirror opposite; but we do not appear to be of our true size; we look like a company of fairies or pigmies. But if any of you take this concave mirror, and look closely into it, you will perceive your image to be exceedingly magnified.

I will now place the mirror in a situation to admit of your image being reflected when you are at a distance from it. With a little care in choosing your position, you will then see an image of yourself, *smaller* than the reality, and appearing in the air between you and the concave mirror, with this whimsical peculiarity, that it seems to be standing on its head. Bend very gently forward, and the image will seem to glide through the air, as if to meet you: extend your hand towards it; bring it close under the head of the image; try to grasp what looks so much like a real object. See! your fingers appear to pass through the phantom, and to close on the unsubstantial air.

From what you have just seen, you may conclude, that if our concave mirror were large enough to reflect the whole figure, and we could invent some means of restoring the phantom to an upright posture, it would make a very respectable apparition—visible to one person only, gliding silently along, and vanishing in the twinkling of an eye. If we could invert *ourselves,* it would answer the purpose: the phantom would then be upright; but as I suppose that none of the present company can practise such a feat, I will show you the effect with an object which can be inverted.

I take this bottle, partly full of water, and corked: when placed before the concave mirror, it appears, like the phantom you have seen, to be inverted. I reverse the bottle: the reflected image now seems upright; and the water, which is in the neck, looks as if it were suspended by magic. Now I invert the bottle, and the phantom in the air immediately becomes upright. I uncork it; and while the water is running out, the image appears as if some one was pouring water in from above, to fill it. When the bottle is empty the illusion is at an end.*

The reason why an object when placed very near a concave mirror is magnified, and diminished when placed at a certain distance, is this: in the magnified image, the object reflected is

* Joyce, ib. p. 118.

placed between the focus and the surface of the mirror. The image then appears *behind* the mirror, upright, curved, and very much magnified. But if we place the object, as we have done just now, so distant that the focus of the mirror shall be between the object and the glass, then the image will be formed in the air before the mirror.*

I recollect, many years since, going to see an exhibition in London, which consisted of many curious deceptions, produced by a concave mirror. It was so contrived, that the spectators did not see the mirror, or the real object reflected in it; both these were behind the partition of an inner room, where the object was strongly illuminated by a lamp. The outer apartment was darkened, and one person at a time was requested to look into a glass placed in the partition. An image then appeared in the air, between the eye and the glass: the figure of a man in a long, loose gown, who seemed to extend his hand and offer you a nosegay; it looked so

* Ibid, v. p. 119 and 121.

natural, that the spectator attempted to grasp it, to the great amusement of the bystanders, who could see nothing; as you know was the case with yourselves just now, when one of you was trying to grasp her own inverted image. In the exhibition I am describing, the image was not inverted; the whole appearance was like reality. The phantom withdrew the nosegay, and again extending his hand, presented a bird. That too was withdrawn, and he offered the ivory handle of a dagger; but when the spectator extended his hand to receive it, the phantom suddenly turned the dagger, and made such a natural *thrust* with the point of it, that every person of the party, who saw it in succession, started back, though a few minutes before they had been laughing at their companions for grasping and starting at nothing. I cannot exactly tell you how this deception was managed, for the audience, as you may suppose, were uninitiated persons, to whom none of these mysteries were revealed; but I am inclined to think that the phantom was the reflected image of an automaton, whose motions were secretly regulated by the exhibitor himself.

Another part of this optical entertainment, was a view of Scarborough, a sea-port town in Yorkshire, frequented as a bathing-place. It stands in the recess of a beautiful bay, on the shore of the German Ocean. The town rising from the water's edge in the form of an amphitheatre; the ruins of the ancient castle, crowning the top of a lofty promontory; and the wide expanse of ocean, were the striking features of this magic picture. Like the phantom, it was visible only to those who looked through a glass or lens, which was fixed in the wall of the apartment, and appeared to be a small window, hung round with drapery. While you were looking at the town, and admiring its picturesque situation, the scene, which resembled a real view rather than a painting, became gradually darkened; heavy clouds overspread the serene, blue sky; and the gloom increased to a deep obscurity, through which no outline could be distinctly traced. Suddenly the darkness was dispelled by the most beautiful imitation of lightning I ever saw; momentary flashes, showing the cliffs and buildings of the town, just as they might have done in reality. The clouds soon passed away, and the prospect again appeared to be illuminated by the cheerful light of the sun.

There is no doubt that such a deception may be produced by a magnifying lens, and the skilful management of a lamp placed behind a picture, painted as a transparency. It was probably by a similar contrivance, that Cornelius Agrippa exhibited the "ladye of his heart" to Lord Surrey; and as we have in this Lecture been pretty much confined to a literal account of the effects produced by reflection and refraction, I think we may now be permitted to admire the imagery, which the operation of these powers has suggested to the imagination of a poet.

'Twas All-Soul's eve, and Surrey's heart beat high;
He heard the midnight bell with anxious start,
Which told the mystic hour approaching nigh,
When wise Cornelius promised, by his art,

To show to him the ladye of his heart :
Albeit betwixt them roared the ocean grim ;
  Yet so the sage had hight to play his part,
That he should see her form, in life and limb,
And mark if still she loved, and still she thought of him.

Dark was the vaulted room of gramarye,
  To which the wizard led the gallant knight ;
Save that before a mirror, huge and high,
  A hallowed taper shed a glimmering light
  On mystic implements of magic might,
On cross, and character, and talisman,
  And almagist, and altar, nothing bright ;
For fitful was the lustre, pale and wan
As watch-light by the bed of some departing man.

But soon within that mirror, huge and high,
  Was seen a self-emitted light to gleam ;
And forms upon its breast the Earl 'gan spy,
  Cloudy and indistinct as feverish dream ;
  Till slow arranging and defined, they seem
To form a lordly and a lofty room,
  Part lighted by a lamp, with silver beam,
Placed by a couch of Agra's silken loom,
And part by moonshine pale, and part was hid in gloom.

Fair all the pageant—but how passing fair
  The slender form which lay on couch of Ind !
O'er her white bosom strayed her hazel hair ;
  Pale her dear cheek, as if for love she pined,
  All in her night-robe loose she lay reclined,
And pensive read, from tablet eburnine,
  Some strain that seemed her inmost soul to find :
That favoured strain was Surrey's raptured line ;
That fair and lovely form, the Lady Geraldine.

Slow rolled the clouds upon the lovely form,
  And swept the goodly vision all away——

It is by no means an improbable supposition, that the mirror in that "vaulted room of gramarye" might be, strictly speaking, not a mirror, but a lens, similar to that through which the view of Scarborough was contemplated. A poet is not obliged to be minutely accurate; and, in this instance the rules of his art required him to magnify the power of the wizard.

The incident is, however, said to have really happened to the earl of Surrey, while on his travels; and the poetical description does not exaggerate the power, which, in the days of Henry the Eighth, was ascribed to Cornelius Agrippa, as a magician and astrologer, who was accused by his enemies of holding frequent intercourse with departed spirits.*

We have reason to be glad that we live in an age when the general diffusion of knowledge, and juster views of religious truth, would prevent any man from laying claim to magical power, or his enemies from bringing a charge against

* Scott's Lay of the Last Minstrel, note, p. 336, and Lempriere's Universal Biography.

him, that would be rejected by common sense; but though we enjoy greater advantages than were possessed by our countrymen in the days of Cornelius Agrippa, we should remember that the knowledge of other people avails us little, till, by study and reflection, we make it our own. Some diligent persons have done much more than this; and, when next I have the pleasure of seeing you, we shall notice several, who, by improving the inventions and extending the discoveries of others, so greatly enlarged the bounds of knowledge, that they are deservedly regarded as benefactors to mankind.

LECTURE IV.

SPECTACLES AND TELESCOPES.

ARTICLES LAID ON THE TABLE.

A POCKET TELESCOPE.
AN ASTRONOMICAL TELESCOPE.

LECTURE IV.

SPECTACLES AND TELESCOPES.

In our last Lecture, we began to consider the advantages resulting from the *transparency* of glass. I told you that we are indebted to Sir Isaac Newton's observations on the sun's rays passing through a prism, for the important discovery of the nature of light and colours. We noticed the intense heat produced when these rays are collected into a focus, either by refraction or reflection; and some curious optical deceptions, occasioned by the diverging, converging, and crossing, of certain rays of light. We amused ourselves with the *effect*, without fully explaining the *cause*, for the clear understanding of which, some acquaintance with the simplest truths of geometry is requisite. Whenever we shall have attained this preliminary knowledge, we may go farther into the subject.

But though our inquiries and explanations are, for the present, confined within narrow bounds, many interesting facts may be so far comprehended, that I hope, nay, confidently anticipate, that some among you will not be satisfied with your present measure of knowledge, but stimulated to overcome a few difficulties, in order to facilitate your future progress.

I propose this evening to notice some of our obligations to flint-glass, which, on account of its superior power of refraction, and its great purity and clearness, is generally employed for the lenses of those beautiful instruments, which reveal to us the hidden wonders of our own world, and enable us to observe the motions and appearances of the heavenly bodies. When the Sidonians and Tyrians were making their first experiments, in hopes of reproducing the transparent substance accidentally discovered in the ashes of a fire, they little imagined that the shapeless mass they succeeded in obtaining, would not only be purified and moulded into various forms by themselves, but that, in future times, the discovery they had made would prove the means of enlarging the boundaries of human knowledge, to an extent far beyond their powers of comprehension; and that it would also add to the happiness of man, by prolonging to him the enjoyment of the most valuable of his senses!

As the invention of spectacles preceded that of telescopes or microscopes, and is, in fact, of more importance than either of them, we will speak of it first; and I am really sorry that I cannot tell you the name of the person who conferred so great a benefit upon his fellow-creatures. Dr. Hutton thinks it probable that the first hint was derived from Alhazen, an Arabian author, who wrote about the year 1100,* or from our own countryman, Roger Bacon. There is certainly a passage in the works of the

* Hutton, ib. ii. p. 176.

latter, in which he speaks of crystals, or glasses, of a convex form, being useful to old persons, whose sight is weakened; enabling them, when reading, to see the letters of a larger size, and more distinct in form than they could without such assistance. On the strength of this and some other passages, the invention of reading-glasses has been ascribed to Bacon; but others have disputed his claim to that honour. It seems, however, pretty certain, that the invention of spectacles led to that of telescopes; and also, that this last discovery was made accidentally. I have somewhere read an account of the circumstance which may interest you—but have forgotten the authority, and can only relate it from memory.

It has been said, that the children of Zacharias Jansen, a spectacle-maker of Middleburgh, were one day amusing themselves in their father's shop with some lenses which were lying there; they took them to the door, and were spying through them at different objects in the street, when one of the children happened to place two lenses in such a situation, that, on looking through them, the spire or tower of a church at some distance, was seen as if it were close at hand. Surprised at such an appearance, the children called their father, and desired him to look at it. Jansen thought the fact so curious, that he contrived to fix the glasses so as to form a telescope about sixteen inches long, which he presented to prince Maurice, of Nassau, probably as an amusing toy, without being aware of the importance of the discovery.*

No particular use seems to have been made of his invention by Jansen; but the circumstance was talked of, and soon reached the ears of a greater man. Any new fact connected with the use of glass, was likely to be immediately known in Venice, where the manufactory of glass was so well understood. Galileo happened to be there: he heard that a sort of optic glass had been made in Holland, which brought objects nearer to the eye; and after reflecting a

* The circumstance is mentioned, but with fewer particulars, in Arnott's Elem. of Physics, ii. 295.

good deal upon the subject, he ground two pieces of glass into the form he thought most likely to answer the purpose, and fitted them to the ends of an organ pipe: with this simple instrument he ascended the tower of St. Mark, and showed at once to the Venetians the wonders of this new invention. From that time he devoted himself wholly to improving and perfecting the telescope, which derives its name from two Greek words, descriptive of its powers, *tēlĕ,* far off; *scŏpe,* a survey. A telescope is designed for the *survey of distant objects.**

The first telescope made by Galileo, magnified only three times; but he soon improved upon it, and made another, which magnified eighteen times: afterwards, with great trouble and expense, he constructed one which magnified thirty-three times. The principle in all was the same; only two lenses were employed; one, called the object-glass, filled the farther end of his tube, in order to collect the rays proceeding from the object he wished to view. This

* Chambers' Dict. and Hutton. ii. p. 567.

lens was plain, or flat, on one side, and convex on the other. At the end of the tube nearest to the eye, he fixed another lens, plain on one side, and concave on the other.

I told you, in the last Lecture, that rays, after passing through a convex lens, are refracted, or change their direction, drawing nearer and nearer to each other, till they meet in the focus. Galileo placed his concave eye-glass, so as to intercept the converging rays proceeding from the object-glass, *before* they reached the focus; in passing through the concave lens, their direction was again changed; the rays no longer converged, but diverged and passed onwards to the eye of the spectator. This telescope had considerable power, but did not magnify so much as if the eye-glass had been a convex lens. Another inconvenience was produced by the divergence of the rays:—you know the pupil of the eye is a small aperture, or opening, and many of the rays were spread too widely to enter the pupil. The consequence of this was, that with a telescope so constructed, the spectator could command only a small space. The space, or area, that can be surveyed at once through a telescope, is called, "*the field of view.*" Galileo's field was a small one; he was therefore obliged frequently to shift his telescope; and later philosophers may wonder at the patience and address he must have exercised, to make the discoveries by which his perseverance was so gloriously rewarded.*

A third inconvenience resulted from the construction of Galileo's telescope. Every object seen through it appeared to be inverted, like the phantoms with which we amused ourselves in the last Lecture. Men, churches, trees, all were seen upside-down. This was a very awkward circumstance in looking at terrestrial objects, but not of much consequence to Galileo, who desired, above all things, to apply his new invention to the observation of the stars.

What words can express the delight he felt, when he first directed his improved telescope,—that which magnified thirty-three times,—to the

* Hutton, ib. Arnott, ii. 295.

heavens, and through it contemplated so many glorious objects, which no human eye had ever before seen! There he beheld Venus, no longer appearing only as a beautiful morning and evening star, but like another moon:—first a slender crescent,

> "Like a silver bow,
> New strung in heaven, she lifts her beamy horns;"

then passing onward in her orbit, the crescent became broader, then a half circle, till at length its whole illuminated surface being opposite to the earth, it presented the appearance of a moon at the full. Galileo might previously have supposed this was likely to be true, but now he saw it with his own eyes, as distinctly as he could observe the changes of the moon. When Venus is between the earth and the sun, she becomes invisible to the inhabitants of our planet, just as the moon does when in the same situation, because their dark sides are next to us.—It is then new Moon, and new Venus. When the moon is so circumstanced, it sometimes hides a part or the whole of the sun's disk, and this we call an eclipse of the sun. The same thing occasionally happens with Venus, but she is at so great a distance, that we cannot see it without the help of a telescope: through that instrument she has been observed passing over the sun's face, like a little black spot. This is called the *transit* of Venus:—*transit, transition,* and other words of the same kind, come from the Latin, and express a passing over, removal, change of state, or place.

I cannot now explain to you the important discoveries which have been made by observing the transit of Venus: it has enabled later astronomers to determine, with great accuracy, the distance of the earth from the sun; and having discovered this, they easily found the distances of the other planets. As soon as you know the rule of three perfectly, you may go on to the higher parts of arithmetic; and when you can extract the cube-root, you may make these calculations yourselves.* I mention this, because many young ladies think, that if they were to

* Joyce, Sci. Dial. ii. 203. 206.

go beyond the first rules of arithmetic, such knowledge would be of no *use* to them. You certainly will not want it to reckon the value of so many yards of ribbon or muslin; but if you delight in contemplating the works of Providence, surely you must feel pleasure in every improvement of the faculties, which may enable you to form some faint conception of the laws by which the universe is governed. You will then no longer see "the moon walking in brightness," or the stars appearing one after another in the evening sky, without experiencing something of that sweet and solemn feeling, which led the Psalmist to exclaim, "*The heavens declare the glory of God, and the firmament showeth his handy work.*" These testimonies of his power and goodness are not shown here to one, and there to another; "There is no speech nor language where their voice is not heard." Let our situation in life be what it may, to all who are blessed with a good education, the great volume of nature is opened:—we all know enough to enable us to study it more; and every page we read presents us with fresh occasions of wonder and delight.

We left Galileo looking through his telescope at the changing aspect of Venus, and he might previously have imagined that such an alteration in her appearance must take place; but when the astronomer directed his tube towards Jupiter, he saw that of which he could have had *no* conception: he perceived this noble planet to be accompanied by four moons, which revolve round him at different distances, and in different periods of time. Nor was this a mere spectacle to be admired, without leading to any important result. The eclipses of the moons of Jupiter have enabled astronomers to determine the longitude of different places on the earth.

Perhaps I may be able to give you some notion of the way in which this is done. No doubt some of you have learned, while studying your problems on the globe, that *every hour answers to fifteen degrees of the equator.* If you look at the map of Europe, you will see that the first meridian—that from which we reckon our degrees of longitude—passes over London; (to speak quite correctly, I should say over the Royal Observatory, in Greenwich Park;) and that the fifteenth degree passes over Mount Etna. Now suppose the sun to be exactly *south* of Etna; it is then noon-day to the inhabitants of that mountain, and, at the same moment, it is eleven o'clock in the morning to the astronomer at Greenwich. The earth must continue turning on its axis for one hour, before the Observatory at Greenwich will be exactly opposite to the sun:—it will then be *noon* at Greenwich; and Mount Etna having also passed on towards the east, the sun will begin to shine on its western side:—it is then *one in the afternoon* to the inhabitants of Etna.

We will now, if you please, suppose that one of the satellites of Jupiter is going to be eclipsed, and that two astronomers, one at Greenwich, and the other on Mount Etna, have their telescopes in readiness to observe the phenomenon. They will both see the eclipse at the same moment of time; but if the English observer finds, on looking at his watch, that it is seven o'clock in the evening, the watch of the Sicilian will show him that it is eight o'clock. This difference of an hour in the watches, which we suppose to be equally well regulated, shows that there are fifteen degrees of longitude between the two places.

Perhaps you may say that Greenwich and Mount Etna are so widely distant, that neither of the observers could know what the other was doing. They might, however, have agreed to make such an experiment, because the time of eclipses may be calculated beforehand. Astronomers have observed these satellites so accurately, that they can tell how long they are in revolving round Jupiter, when they will pass into his shadow, and how soon they will reappear on the opposite side of that beautiful planet. You know that in a common almanac, the time of the rising and setting of the sun for every day in the year is carefully noted; and thus, in the Nautical Almanac, there are printed tables, showing the time of these eclipses.

A person possessing this book, a good telescope, and a well regulated watch, in whatever part of the world he happens to be, may direct his telescope to Jupiter, and observe the difference of time between his watch, at the moment of the eclipse, and the hour and the minute in the printed table, which is computed for the meridian of Greenwich: he must then allow fifteen degrees for every hour of difference; and thus he may easily find the longitude of any place on *land.* Unfortunately for sailors, who stand most in need of such knowledge, the rolling of the ship often makes it impossible to fix a telescope properly. If the satellites of Jupiter could be seen distinctly with the naked eye, the longitude might be found by a common sailor, with nearly as much ease and certainty, as the latitude; but as no method has yet been devised for rendering the telescope independent of the motion of the vessel, they are obliged to have recourse to other means.

An eclipse of the moon, like those of the satellites of Jupiter, may be seen from every part of the earth, where the moon is above the horizon, and seen with the naked eye. This, then, seems the very thing that is wanted for the sailor; he may find in his Nautical Almanac, the hour and minute of the eclipse at Greenwich, and turn the difference of time into degrees of longitude. It seems so; but this method does not fully answer the sailor's purpose. Eclipses of the moon happen too seldom to be of much service; and when they do happen, the beginning and end of the eclipse cannot always be so clearly distinguished as to prevent error in observing the time, which may occasion error in reckoning the longitude. The satellites of Jupiter, on the contrary, are so quick in their movements, and pass so often into the shadow of the planet, that there is scarcely a night in which one or other of them is not eclipsed. Beside this advantage, they enter the shadow, and emerge from it so suddenly, that the *time* of the phenomenon may be observed much more accurately, and therefore the distance may be calculated with greater exactness.

But this is of little use to the sailor, whose bark is tossing on the ocean; and the traveller who is crossing pathless deserts, cannot always avail himself of his better opportunity of adjusting his telescope; for, during part of the year, Jupiter is invisible. The sailor and the traveller may, however, obtain the information they desire, by observing the moon, not when she is eclipsed, but any evening, if she is not obscured by clouds. I believe that some of you are acquainted with the principal constellations, or, at least, with the brightest of the fixed stars; and you may have observed that the moon is continually changing her place with regard to them. If this evening, at eight o'clock, she is near any particular star, to-morrow, at the same hour, she will appear considerably to the east of it. This does not take place at random; the laws which regulate her motion are so well understood, that her position, with regard to the principal fixed stars, is calculated for the coming year, and printed in the tables I have mentioned. The traveller or the sailor may, with an instrument called a quadrant, find the distance of the moon from any remarkable star, and notice the exact *time* of his observation. He must then look into the Nautical Almanac, where he will see what o'clock it is at Greenwich, when the moon and that star there appear to be at the same distance from each other. He must compare it with the time of his own observation. If his watch is *earlier* than the printed table, he knows he must be on the *west* of Greenwich: if it points to a *later* hour, then he is somewhere to the *east;* and by allowing fifteen degrees to each hour of difference, he will find his own situation, in east or west longitude, as it may happen.*

There is yet another method which, perhaps, may surprise you. You are accustomed to look at the clock, to learn the hour of the day, but probably are not aware that such a machine, if it could be made to go with perfect accuracy, would afford the easiest method of discovering the longitude. To whatever part of the world it

* Bonnycastle's Astronomy, Lett. x.

might be carried, the observer who consulted it at noon, would see what o'clock it then was at Greenwich: he need only turn the difference into degrees, and his work would be done. It is easy to perceive the advantages of this method of finding the longitude, and its great importance to a mercantile nation like the English; but very difficult to make a clock that would keep time in all climates, and not be affected by the irregular motions of the ship. Parliament offered a reward of twenty thousand pounds, to any ingenious man who would persevere till he accomplished such an undertaking; and John Harrison, the son of a carpenter, determined to try. He made two clocks, mostly of wood, which went far better than any that had been seen before, hardly erring a second in a month. He tried again and again, in hopes of producing something that might be depended upon at sea. At length he completed a time-piece, in the form of a watch: a monstrous one, indeed, for it measured six inches across! This was thirty-five years after he had made the wooden clocks; and, in the meantime, his son William had grown up. Harrison entrusted the precious watch to his care; and he made two voyages with it to the West Indies. It performed admirably; and the inventor received, at different times, more than the promised reward.*

Harrison was satisfied with a plain English name for his machine: it was called *the time-keeper.* The taste of the present day is not so simple: such watches are now called *chronometers,* from two Greek words; *chrŏnŏs,* time; *mĕtrĕō,* I measure. They are not, however, *perfect* measurers of time; though the best of them make a near approach to perfection. I have been told that an ingenious person has lately constructed a chronometer which promises still greater accuracy, by substituting *very fine glass* for metal, in the regulating spring of the machinery. And thus this beautiful composition, which, by its transparency and power of refraction, enabled Galileo to discover the satellites of Jupiter, will, it is hoped, from not being

* Hutton, i. 586, ii. 54.

affected by changes of temperature, or liable to contract rust, give such precision to the *rate,* or uniform movement, of chronometers, that sailors may, in future, have no difficulty in finding the longitude with exactness.

By means of the eclipses of Jupiter's satellites, it has also been found possible to measure the progress of light. What we call *a ray,* is a particle of light, set in motion and passing onwards. It is computed that rays of light come from the sun to the earth in eight minutes; that is, nearly at the rate of twelve millions of miles in one minute!

It would detain us too long to follow Galileo through all the discoveries he made with his imperfect instrument. Notwithstanding its inconveniences, and some suggestions as to the way in which it might be improved, no better telescopes were made for more than thirty years. At length, Father Scheiner, a learned Jesuit, substituted a convex eye-glass for the concave one of Galileo's telescope. He thus obtained a larger *field of view;* that is, the part of the heavens, or of the landscape, which could be seen at once, without moving the eye or the instrument, was more extensive; but the objects were still inverted,* which was very inconvenient when the instrument was employed in the examination of objects on the earth.

Scheiner considered the matter further, and at last found an expedient which removed that difficulty. In order to avoid the awkwardness of seeing objects upside down, he added a second convex lens to the eye-glass, which, by inverting the image *before* it reaches the lens nearest to the eye of the observer, causes it, after being, as it were, set upright again, by passing through that lens, to appear in its natural position. It is surprising that forty years should have elapsed from the first invention of telescopes, before any one thought of adopting so simple an expedient.†

You will understand it better if I take this pocket-telescope to pieces, and show you the parts, than by seeing lines drawn upon paper.

* Hutton, ib. 569. Joyce, Sci. Dial. ii. 218.

† Hutton, ib. 570. Arnott, ii. 292.

A telescope is merely a long tube, blackened within to destroy useless light, and fitted up with the lenses I am going to show you. First, in the large end is the object-glass, the window that admits the view: at the opposite end of the small tube that slides within the large one, you see there is another lens: this is the eye-glass; and in telescopes containing only these two lenses, the objects seen are always inverted, as they were in Galileo's instrument.

Before we proceed farther, I would observe, that although this telescope consists of four tubes, sliding one within the other, such an arrangement has no other effect than to make the instrument more portable. *One* slide, indeed, is necessary, because it enables each observer to adjust the focus so as exactly to suit his own eye; but the repetition of slide within slide, like this, is merely for convenience: when the tubes are all slipped back, the telescope may be easily put into the pocket.

You may form a good idea of the necessity for Scheiner's first improvement on the Galilean telescope, by looking through the large one on the table, in its present state. You will see the trees in the orchard before us appear beautifully distinct: you may even distinguish the veins in their leaves; and by screwing on this small magnifier in front of the eye-glass, we can increase its power. But the objects are still *inverted;* and, therefore, a glass of this construction is fit only for viewing the *heavenly bodies.* It is called an astronomical telescope.

When we desire to use the instrument for viewing terrestrial objects, we must take out the eye-glass, and substitute a tube like this. The lenses it contains, restore the objects to their natural position: they are an improvement on the original invention of Father Scheiner.

Perhaps it is in consequence of the first, or Galilean telescope, having contained only two lenses, which were called the object-glass and the eye-glass, that when Father Scheiner added a third lens, and soon afterwards Father Reita added a fourth, these were still considered as belonging to the eye-glass; and they do, in fact, assist the eye, by restoring the natural position and rendering, more distinct, the image transmitted through the object-glass. Therefore, considering all these three lenses as appropriated to the service of the eye, the telescope is still said to consist of the object-glass and the eye-glass.

An instrument of this construction is called a land, or day telescope. It is adapted for viewing objects in the day-time, on or near the earth. It enables the sailor, whose unassisted eye can only perceive a small speck in the horizon, to discover what kind of vessel is just rising above the convexity of the earth. He may distinguish to what nation she belongs; and, by aid of mutual signal-flags, hold converse with the distant crew.

And thus a man, in the midst of a solitary plain, on the top of a mountain, or even in his own garden, or near some open window in his house, who supposed himself unseen, might yet, by a telescope, be instantly placed under the observation of any person who chose to watch him. It is said that some remarkable instances have occurred, in which actions, imagined by the parties concerned to have been performed in perfect secrecy, have thus been made known.*

Would any person be deterred from unworthy conduct by such a thought? How much more impressive should be the conviction, that we are perpetually beneath the notice of an Eye, which needs no lens to assist its powers, but sees "in all dark places, by night as well as by day!"

One of the great difficulties with which the first makers of telescopes had to contend, was occasioned by the separation of the rays of light into the distinct colours of which they are composed. The lens which was so useful in refracting the rays, and converging them to one point, or focus, had also the property of dividing them, like a prism; and, in consequence of this, the image formed behind the lens was surrounded by coloured fringes, which made it

* Arnott, ii. p. 290.

indistinct, especially when the object viewed was small.

This was justly regarded as a great imperfection, and much consideration was bestowed on the best means of rectifying it. One very ingenious person fell into the right train of thought, and made a great discovery; but it seems that he did not publish it for the general good.* At length Dollond, the optician, after many experiments, found that different kinds of glass, as crown-glass, and flint-glass, differ greatly in their powers of refracting the rays which pass through them, so as to produce coloured fringes. He made his first experiments with prisms, placing them together, but in opposite directions, so that the refraction of one should counteract the refraction of the other; and he had the pleasure of finding that the light which passed through them was not separated into distinct colours, but remained perfectly white. This discovery he thought might be applied to the improvement of the

* Hutton, i. 26.

object-glasses of telescopes; and that lenses of flint and crown-glass might be so adapted to each other as to produce the same effect. He employed three lenses for this purpose; the middle one was of flint-glass, and concave on both sides; the two outer ones were of crown-glass, and convex on both sides. When these are placed close together, they form, in appearance, one very thick, double convex lens, like the object-glass of this telescope; and the light which passes through it is perfectly colourless. How great must have been the pleasure of Dollond, on seeing the successful result of his experiment! He was also very fortunate in obtaining some glass more suitable for the purpose than any which was then manufactured, or which could be made by known rules. This glass, by some happy accident, was free from the imperfections usually met with; and thus his sagacity, industry, and good fortune enabled him to construct telescopes, in which the images were bright, distinct, and free from the coloured fringes which had been so great an annoyance in former instruments. Dollond gave his improved telescope a name founded on that quality he had taken so much pains to obtain. Like many other philosophers, he made choice of Greek words to express the peculiar excellence of his instrument; *a,* without; *chroma,* colour; and called it an *achromatic* telescope.*

The perseverance of Dollond seems to have equalled his ingenuity. He thought that telescopes might be still farther improved, by increasing the number of lenses; and that a large field of view might be thus obtained, without lessening the distinctness of the image He made one accordingly, with an object-glass composed of three lenses, such as I have described; two convex, of crown-glass; and one concave, of flint-glass. It was also furnished with two tubes for eye-glasses. One tube contained four lenses, to be used for looking at objects on the earth. The other tube had two lenses, and was intended for astronomical purposes. The instrument before you has the name of a different maker, but appears

* Hutton, i. 25. Arnott, ii. 296.

to be constructed exactly on Dollond's plan. We will take both the tubes to pieces, that you may see the arrangement of the lenses. The telescopes most in use at present are of this kind. When first invented they were much admired, at home and abroad; and Dollond and his sons continued to make them of different powers and sizes. One was so contrived, that all the different parts are put together and contained in a tube four inches and a half long; yet, small as it is, the instrument is so powerful, that the moons of Jupiter and the ring of Saturn might easily be seen through it, though the magnifying power was not very great.* In these telescopes the image is formed by lenses, and on the principle of refraction.

During the gradual progress of improvement in the construction of telescopes, it was found that employing mirrors as well as lenses would be attended with great advantage. Those I have been describing, which contain lenses only, are called refracting telescopes. When they were

* Hutton, ii. 575.

required to magnify very much, the tube was obliged to be inconveniently long. In order to magnify twice as much as before, with the same light and distinctness, the telescope required to be lengthened four times; to magnify thrice as much, it must be nine times the length; and so on: therefore it is evident, that if a very highly magnifying power were required, the tube must be so long that it would become unmanageable; but when two concave mirrors are employed to receive and reflect the rays proceeding from the object, and the image thus formed is magnified by the interposition of suitable lenses, through which it is transmitted to the eye, a reflecting telescope, six feet long, will magnify as much as a refracting one that measures a hundred feet. How far improvement may yet be carried, we cannot tell. The refracting telescope with which Galileo discovered the satellites, or moons of Jupiter, magnified thirty-three times. The grand reflecting telescope of Dr. Herschel magnifies six thousand times. It cost him four years of persevering exertion to complete it; but he was speedily rewarded. Soon after, some say on the very day it was finished, he discovered the sixth satellite of Saturn;* and, a few months afterwards, the seventh. Astronomers of the present day hope that new discoveries may yet be made by means of what they call a *fluid-lens,* (that is, a lens composed of two glasses, with a liquid between them,) if king William the Fourth will extend such patronage to the inventor as Dr. Herschel experienced from George the Third.†

* Dr. Hutton and Joyce do not exactly agree on this point.

† See Ency. Brit. new edit.

LECTURE V.

MICROSCOPES AND CAMERA-OBSCURA.

ARTICLES LAID ON THE TABLE.

POCKET MAGNIFYING-GLASS.
COMPOUND MICROSCOPE.
CAMERA-OBSCURA.

LECTURE V.

MICROSCOPES AND CAMERA-OBSCURA.

As the telescope derived its name from affording a view of *distant* objects, the Greek word *mikrŏs,* small, was appropriated to that instrument, which is especially designed for taking a view of *small* things. Any contrivance which renders minute objects visible and distinct, by enabling us to look at them very closely, is, in fact, a *microscope,* though we are in the habit of using that word as the name of a complicated instrument.

You know that a man at the other end of the street, or a house viewed at the distance of half-a-mile, appears very much smaller than any man or house is in reality; but are you aware that if you could see any small object, a fly, for instance, when it was almost close to your eye, it would appear larger than the distant house or man. You think, perhaps, that an object will not appear magnified unless we look at it through a magnifying-glass; but I will convince you that this is a mistaken notion.

Probably none of you can read if you hold a book within six inches of the eye; but if you are enabled to distinguish the letters at half that distance, they will appear to be twice the size, even though no magnifying-glass is employed. I have pricked a hole in this piece of brown paper; will one of you take a book and try to read, by looking through it? Here is no lens, no contrivance, but a simple pin-hole; and the letters appear magnified, only because you are enabled to distinguish them at a shorter distance. I have now made a hole with a much smaller pin; and you will find that the letters are still more magnified, but less distinct than before, because too little light passes through that minute hole to form a clear image in the eye; but if we could contrive to fix a globule of glass in the pin-hole, that tiny lens would collect many more rays of light; and after passing through the lens, these rays would produce an image, magnified to a degree that would quite surprise you; for, the smaller the lens the greater is its magnifying power.

Dr. Hooke, who bestowed much time and pains on the manufacture of minute lenses, has given a very distinct account of the method he pursued in making them.

In the first place, he took a very narrow, thin slip of clear glass, melted it in the flame of a candle or lamp, and drew it out into exceedingly fine threads. The end of one of these threads he again melted in the flame, till it ran into a very small drop: when this drop, or globule of glass, had grown cool, he fixed it in a thin plate of metal, carefully placing the middle of the globule directly over a small hole in the plate. This was a single microscope; and what do you suppose was its magnifying power? You will scarcely believe it to be possible, but Dr.

Hooke asserts, that in this way he made lenses by which he could distinguish particles so small that a million times a million of them would hardly be equal, in bulk, to the smallest grain of sand.*

Notwithstanding this extraordinary magnifying power, there are some important objections to the use of these small globules. They show only a very minute part of the object, strain the sight of those who look through them, and do not admit so much light as a double convex lens. For these reasons they are not often used.†

As the form of a convex mirror is already familiar to you, there can be no difficulty in understanding what is meant by a double convex lens. You have only to suppose a corresponding convex surface on the opposite side. But here is the real thing, which will make it clearer than any description: it is called *double convex*, because it has *two* convex surfaces. You may pass it round, if you please, and observe, for yourselves, its power of magni-

* Joyce, Sci. Dial. v. 203. † Joyce, Dial. Mic. i. 32.

fying. The power is proportioned to the convexity of the lens: the flatter the lens, the less it magnifies. If the glass were quite flat, it would not magnify at all.* You may take that piece of flat glass and try the experiment. You are now quite sure of the fact; but you do not understand *how* the change in the apparent size of an object is produced. Perhaps this drawing may assist you in forming some idea of it.

The small, black cross represents an object at which the eye is supposed to be looking. The lines drawn from the top and bottom of the black cross to the eye, are intended to express the rays of light reflected from the cross. They meet in the eye, and there form an image very much smaller than the real cross; but, partly from experience, and partly from some means of judging possessed by the mind, though we do not perfectly understand *how* it is exercised, that tiny image appears to the spectator to be of its true size.

* Joyce's Micros. i. p. 31.

Here is another drawing, in which the eye is again represented as looking at the cross through a double convex lens.

The black cross is of the same size as in the first drawing; but the rays reflected from it do not proceed in the same direction to the eye. They pass right onwards to the lens; and, being refracted by passing through it, they converge, till they meet in the focus of the lens, at which the eye is placed. Now, as in the first drawing, where no lens is interposed, the rays of light proceed in *straight* lines to the eye, which being accustomed to receive them in that direction from the objects it surveys, acquires a habit of regarding these rays as if they were always transmitted in straight lines,—hence, in the second drawing, the eye is unconscious of the deception produced by the lens, and continues to look onwards, in the same slanting line by which the ray of light approached the eye after it had passed the lens: (this is represented in the drawing by the dotted line.) The consequence is, that the image of the cross is magnified till it fills the space between those lines which have been prolonged by the imagination of the spectator. The magnified cross is represented by the paler colour. It would appear black to the eye, like the real image; but represented thus, it enables you to see that the size is increased in appearance only: the real image is just the same as in the first drawing. You will experience the same deception if you look at any small object through that double convex lens; because the eye will, unconsciously, prolong the rays in the same direction they fall upon it; and as the rays diverge more and more, till they reach the distance of the object, it will appear to fill the whole opening between them, and consequently to be magnified.

This is the principle of the single microscope, for which only one lens is necessary. It is useful in examining small objects, that do not require to be very greatly magnified; such as parts of flowers, or the seeds of plants. What a source of pleasure a little instrument like this might be, when walking in the garden or the fields! The stamens of a flower, the down of a thistle, or a twig covered with moss, would be found adorned with beauties, of which the unassisted eye has no conception. I have been more particular in describing the single microscope, because it is so cheap, portable, and simple, that any of you may provide yourselves with a lasting amusement, by making it a pocket-companion. Sometimes, in a tortoise-shell case, like this, three lenses, of different magnifying powers, are placed: they may be used separately, or two of the lenses at once, or all three together, according to the degree in which you wish an object to be magnified. Perhaps it is not correct to call this combination *a single* microscope, as it has several lenses; but it resembles the single microscope in showing the object itself: whereas, in that which is usually called the compound microscope, we see, not the object, but a magnified image of it.

The compound microscope generally contains three lenses. By taking this to pieces, I think you will be able to understand how the effect is produced. I will first take the tube in which the glasses are fixed, out of the hollow cylinder in which it slides. This tube is called the *body* of the instrument. I will speak of it presently. The brass plate, with a hole in the centre, is the *stage* on which the object to be viewed is placed for inspection; and the use of the hole is to admit of a strong light being thrown upon the object, by reflection from the concave mirror beneath, which is fixed so that it may be turned in any direction, to collect light from a window or candle. In order that this reflected light may fall upon the object, it is laid upon a plate of glass fitted to the hole in the stage; or, if very minute, it may be confined between two small plates of mica, which, being as transparent as glass, much thinner, and less brittle, is preferred for the purpose. In this little ivory box are some mica plates, ready for use; and in this circular brass plate, pierced with holes to receive them, you see a convenient mode of keeping minute specimens ready for examination.

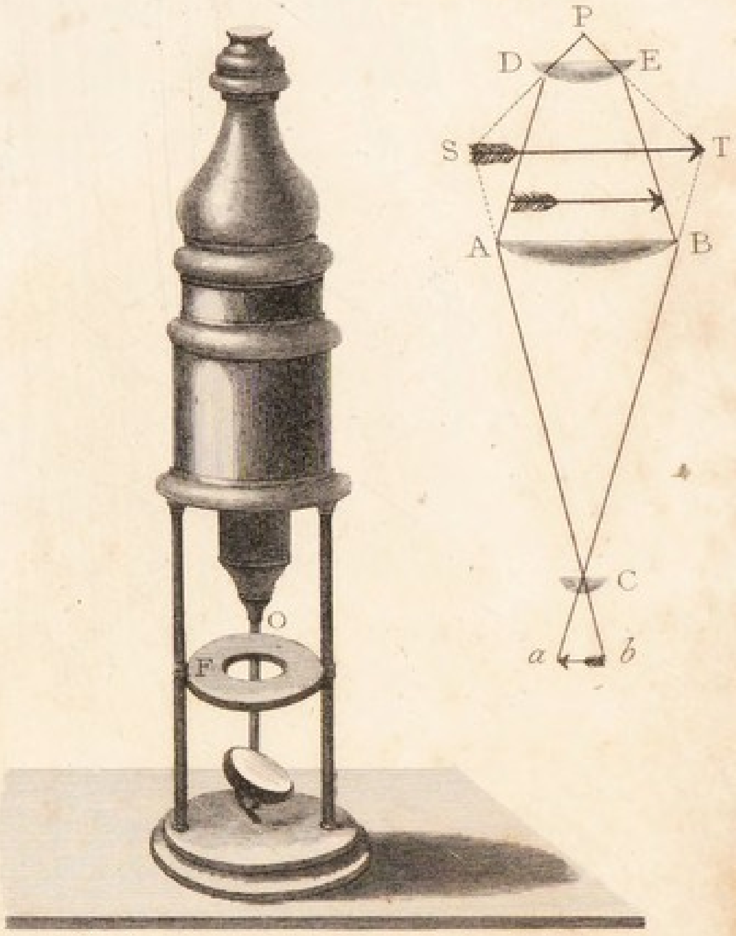
Such are the arrangements made for placing the object and throwing light upon it. We will now examine the tube or *body* of the microscope, which enables us to inspect the object of our curiosity. On the lower end is screwed an object-glass, which is a small, convex lens, of greater or less magnifying power, as may be required for the present purpose. I have already told you, that the smaller the lens the greater its power of magnifying; but it is better you should see the fact with your own eyes, and then you will be certain of it. In this drawer the object-glasses are arranged and numbered, according to their power. In the first or highest power, the lens you see is very small: the part through which light is transmitted is no bigger than the head of a large pin; as the size of the lens is increased, the power of magnifying diminishes. You see that the fifth, or lowest power, is the largest lens of all. With No. 5, applied close to the eye, I can read a word of three or four letters distinctly, and see a space of white paper round the word: but with No. 3, the field of view is so small, that a single letter almost fills the illuminated circle; and with the magnifiers marked 1 and 2, I think you will not be able to distinguish any thing: but take them and try. There is no conviction so clear as that which is produced by our own sensations. When you are satisfied, I will go on.—

We have been using these magnifiers as *single microscopes,* trusting to the power of a single lens, and looking *through* it at the object. We find we cannot use the two highest powers to any advantage: the field of view is too small; the light transmitted too feeble. Yet there is no doubt of the superior powers of these small lenses; and if we could obtain more light, and extend the field of view, we might see all the wonders they are capable of exhibiting.

Now the compound microsope was invented just to obviate these difficulties; and I will show you how it acts. It is unnecessary to repeat what has been already said about the concave mirror, placed beneath it, collecting the rays of light, and throwing them more powerfully upon the object. We will now consider what happens, after the rays have passed through the tiny lens, and up this black tube into the body of the instrument.

After passing through the object-glass, the rays of light diverge, and continue receding from each other, till they reach the top of the cylinder. I will unscrew the body of the instrument just above the cylinder, and show you what is placed there to receive them. Here, you see, is a large convex lens, ready to intercept the rays which had diverged too widely to enter the eye of the observer. By passing through this large lens, the rays are made to converge again, till they reach another lens at the top of the tube. I will take it off, and show it to you.

You perceive that each of these lenses has the power of magnifying, but in different degrees: as in the small magnifiers, so in these; the smaller lens magnifies much more than the


O
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b

large one, and the image of the object to be viewed being formed *between* these two lenses, the rays proceeding from it are made again to converge, on passing through the upper lens or eye-glass, in the focus of which, a distinct and greatly magnified image of the object is seen.

I hope this drawing will make the affair still plainer. The first figure is a microscope, like this we have been examining: the second is a diagram, in which slanting lines show the course of the rays, and the refractions they sustain in passing through the different lenses.

The arrow *a b*, represents any small object, which you may suppose to be laid on the stage of the microscope, as at F. C is the object-glass, such as you have seen screwed on the instrument at the part marked O in the drawing. The rays proceeding from the object, on entering this small lens, are converged. They cross one another, and pass out of the lens diverging: if they met with no interruption, these rays would continue to rise up through the body of the microscope, and would form, in the upper part of it, an image, ST, so large, that only a part of it could be seen at once, by an eye looking in through a lens fixed in the top of the instrument. By using *two* eye-glasses we obtain as large an image, and see the whole of it. They act in this way :—

The first eye-glass, AB, receives the diverging rays, and refracts them, bringing them to a focus at a shorter distance than ST ; an image is accordingly formed there, smaller than ST. The rays, which had been made to converge by passing through the lens AB, go on converging till they reach the second eye-glass DE : in consequence of passing through that second lens, their convergence is increased, and the rays enter the eye of the observer at P.

I told you, when explaining the diagram of an eye looking at a cross, that the eye perceives only the appearance presented to it, and is unconscious of the refraction produced by the lens; regarding the object as if there were no lens at all, The converging lines PD, PE, are therefore prolonged in the same direction to S and T, where the magnified image appears to fill the whole space between those letters.

If it were not for the refraction produced by the second eye-glass, the image would have been only the size of that which you see half-way between ST and AB, therefore, you perceive that *the field of view*, the space which can be commanded by the eye, is enlarged by the introduction of the second eye-glass.

You know that all persons do not see objects clearly at the same precise distance; some are near-sighted, others can distinguish objects a great way off: in order to meet this diversity in the structure of different eyes, the body of the microscope is made to slide up and down in the cylinder, which lengthens or shortens the distance between the eye and the object examined, enabling the beholder to adjust the instrument so as to suit his own eye, and the focus of the object-glass he happens to use.

From what has been said of the two instruments, you perceive that there is a great resemblance between telescopes and compound microscopes; in both we have one tube sliding within another, to adjust the focus to different eyes; in bcth we have an object-glass, filling one end of the tube as a window, to receive and transmit the rays proceeding from the object to other lenses, called eye-glasses, because they assist the eye, by obtaining for it a larger field of view, and still further magnifying the image. And, as there are reflecting telescopes, so there are also reflecting microscopes, in which the image of an object magnified by reflection from a concave mirror, is still further magnified, by being viewed through a double convex lens. Sir Isaac Newton was the inventor of this kind of microscope; it represents the object distinctly, but inverted. So great is the resemblance of structure, that a telescope may be changed into a microscope, by removing the object-glass to a greater distance from the eye-glass;* but whenever the tube is fitted for taking a view of *distant* objects, it s a telescope; when it is adapted for taking a view of *little* things which

* Hutton, ii p. 108

are near to us, it is a microscope. Only bear in mind that *tĕlē* means far off, and *mikrŏs* small, and you can never forget the distinction between names which so clearly express the different purposes for which these beautiful instruments are intended.

Although it is impossible for me to give you an idea of all the ingenious contrivances which have resulted from the discovery of a lens possessing the curious property of bringing together into one focus all the rays that pass through it, I am desirous of showing you another example.

I told you that the telescope and the microscope derive their names from Greek words, expressive of their peculiar properties. The machine we are now about to examine, has a Latin name, camera-obscura, or *dark-chamber;* because the objects it discloses must be seen in a darkened room, or in a box like this, which is a dark chamber in miniature. It is useful in various ways, and may assist us hereafter in explaining the structure of the eye; but just now I mean to confine myself to the entertainment it is capable of affording, by presenting faithful and lively images of objects, not only in their natural colours and proportions, but with their actual motions and varying expressions. The objects passing along a busy street, birds flying, or trees waving in the wind, may form, in the camera-obscura a succession of moving pictures, beyond the power of art to imitate.

The invention is ascribed to John Baptista Porta, a learned Neapolitan, who died in the year 1515. He was fond of the society of persons like himself, and received them at his house; he also studied the curious phenomena of nature; and, as he lived in an age of great ignorance and superstition, he was accused of practising magical arts, and drew upon himself the censures of the Romish church.* Whether he was led by some fortunate accident to contrive this beautiful instrument, I cannot tell you; but it is highly probable, as you may judge

* Lempriere, Univ. Biog.

from an anecdote which was related to me by a young person who witnessed the appearance.

It happened that she got up very early one summer morning, before any one else was stirring, and passed through the small porch or entry of the house; the outer door fronted the east, and through the key-hole streamed a bright ray, which fell upon the whitewashed wall opposite, perhaps about three feet distant. There, to her great delight and wonder, she saw pourtrayed an exact picture of the farm-yard, with the poultry, pigeons, and other animals, in their natural colours; but the magic picture was inverted; the creatures appeared to be walking or flying upside down. The young person who saw this moving scene, was satisfied with admiring so novel a sight, and I dare say would not have thought of any way of setting the images upright; neither would she have invented the means of reproducing such pictures at pleasure. I will now show you how Baptista Porta contrived to do this.

The simplest kind of camera-obscura, and therefore, probably, the first that was made, is formed by placing a convex lens in a hole, cut purposely to receive it, in a window-shutter. You already know that rays of light after passing through such a lens, will converge; therefore, on a white wall or a sheet of paper, placed in the focus of the lens, there will be a beautiful inverted picture of all the objects on the outside, especially if the sun happens to be shining brightly upon them.

In order to see this picture, the observer must however be shut up in the darkened room; and even there he can see only such objects as are before the window: they will indeed be more vivid and distinct than if no lens were employed, but they will be inverted. To obviate this imperfection, recourse has been had to various expedients. I am not sure which of them was adopted by the original inventor; we will now confine ourselves to those which are seen in the instrument before us.

First, you will observe the convex lens, which is fitted into a frame, made to slide backward and forward in the end of the box: by means of the slide, the focus may be adjusted, as it is in a telescope or microscope. You will perhaps inquire, "How are we to see the images when they are inclosed in that box?" I will show you. By lifting up this mahogany flap, we obtain a view of what is going on in the interior of our little, darkened chamber. After the Lecture is over, we will take a view of some of the present company, and you will then see the miniature portraits reflected, not where you would naturally look for them, inverted on the end of the box opposite to the lens, as they were on the wall of the farm-house porch that I mentioned, but in their natural position, on this plate of ground glass; and I dare say you wonder how that reflection can proceed from a lens fixed perpendicularly in the other end of the box. We will remove the horizontal, or level plate of glass, and beneath it we shall discover the mystery.

Here, you perceive, is a plain mirror, or common looking-glass, reclining backward from the lens, which transmits the rays proceeding from the object. The image is reflected in that mirror, and the rays issuing from it are thrown up against the flat plate of ground glass placed to receive them. The objects which are reflected in the highest part of the sloping mirror, are transmitted to that part of the flat glass above, which answers to the bottom of a picture, and this simple expedient restores them to an apparently upright posture. Here, then, you may presently see a perfect miniature resemblance of a person sitting at the other end of the room; a picture which painting cannot equal; for it may speak to, or smile upon you, while you watch every varying expression of the countenance. Or, if by daylight you place the machine before a window, you will have an animated representation of every object before it. I have heard that George Smith, of Chichester, (a painter who obtained great celebrity by his accurate representations of nature, as she appears in our Sussex landscapes,) used to walk about the hills with a camera-obscura, which enabled him to study in detail such objects as were worthy of notice: light, shade, colouring and perspective, were thus placed before him in small, but most faithful pictures.

All who have eyes, and can use them, may be charmed with the representations of the camera. A Malayan chief, in the island of Sumatra, was so delighted with the instrument, when he first beheld it in the possession of a traveller, that he seemed inclined to offer in exchange for it almost any thing he possessed.*

You are sometimes amused by the varied exhibitions of the magic-lantern; but, perhaps, may not quite understand *how* the effect is produced. I will endeavour to explain it.

A lamp is placed within the machine, and a concave mirror fixed behind the lamp, which causes a very bright reflection of the rays issuing from it to pass through a lens placed in the sliding tube. The slips of clear glass, on which the objects are painted, are placed in the tube

* Arnott, El. Phys. ii. 199.

between the lamp and the lens, in an inverted position; and the rays proceeding from these little pictures, after passing through the lens, (which restores the objects to an upright posture,) form magnified images, appearing in circles of light, on the sheet, or screen, which is placed to receive them.

If the screen were made of thin silk, and placed between the lantern and the spectators, and if the slips of glass were so painted that no light could pass except through the figures—the *image only* would be visible, and appear as if it were formed in the air. By removing the lantern farther from the screen, or bringing it closer to it, the figure would be enlarged or diminished, and therefore appear as if it advanced towards the spectator, or retired to a distance. Such a representation is called a phantasmagoria.*

* Joyce, vol. v. p. 220—223.

LECTURE VI.

THE EYE.

LECTURE VI.

THE EYE.

The discovery of glass led, as we have seen, to consequences far exceeding, in importance and beneficial influence, any thing that could have been imagined by those who first combined the ashes of vegetables with pounded rock or sand. In tracing the progress of the art of glass-making, we have observed its application to the structure of those curious instruments, which have unveiled new worlds to the eye of the astronomer, and enabled him to compare the phenomena he observes in them, with appearances in our own planet, of which the causes are well known. How great must have been the pleasure of Herschel, when, directing his telescope to Mars, he saw the polar regions of that planet, overspread with a whiteness resembling the mantle of snow which covers the corresponding part of our globe; or, when he watched, for successive days, those spots of glowing brightness, which seemed to be the burning craters of volcanoes, situated among the lofty mountains of the moon!* All these, and yet greater discoveries, and all the pleasure derived from viewing the minute wonders of creation, we owe to instruments constructed by the ingenuity of man. But there is another optical instrument, nearly allied to the telescope, still more nearly to the camera-obscura, of which, as yet, we have taken no notice, though without it all the others would be useless; and as we began this little series of Lectures, by regarding every thing which claims our notice, as included in one or other of two great classes, as being either a natural or an artificial production, suppose we conclude them by the examination of an optical instrument, curious, beautiful, per-

* Ency. Brit.

fect, far excelling all that has been invented by the art of man—an instrument which became such as we see it by the contrivance of the Divine Artificer, whose power and goodness are as clearly exhibited in the minute perfection, as in the grandeur or immensity of his works.

I suppose it is scarcely needful for me to tell you, that the optical instrument we are about to examine is the eye; but it is very likely that you are surprised at hearing me call it *an instrument.* We shall see, as we proceed, whether the term is not strictly applicable.

In the first place, we will compare the eye with the camera-obscura; beginning with the human eye, as most interesting to us, and afterwards noticing some peculiarities in the eyes of animals.

The striking resemblance of the eye to the camera-obscura, consists in the light being admitted through a double convex lens to a dark chamber, in which the image is formed by reflection.

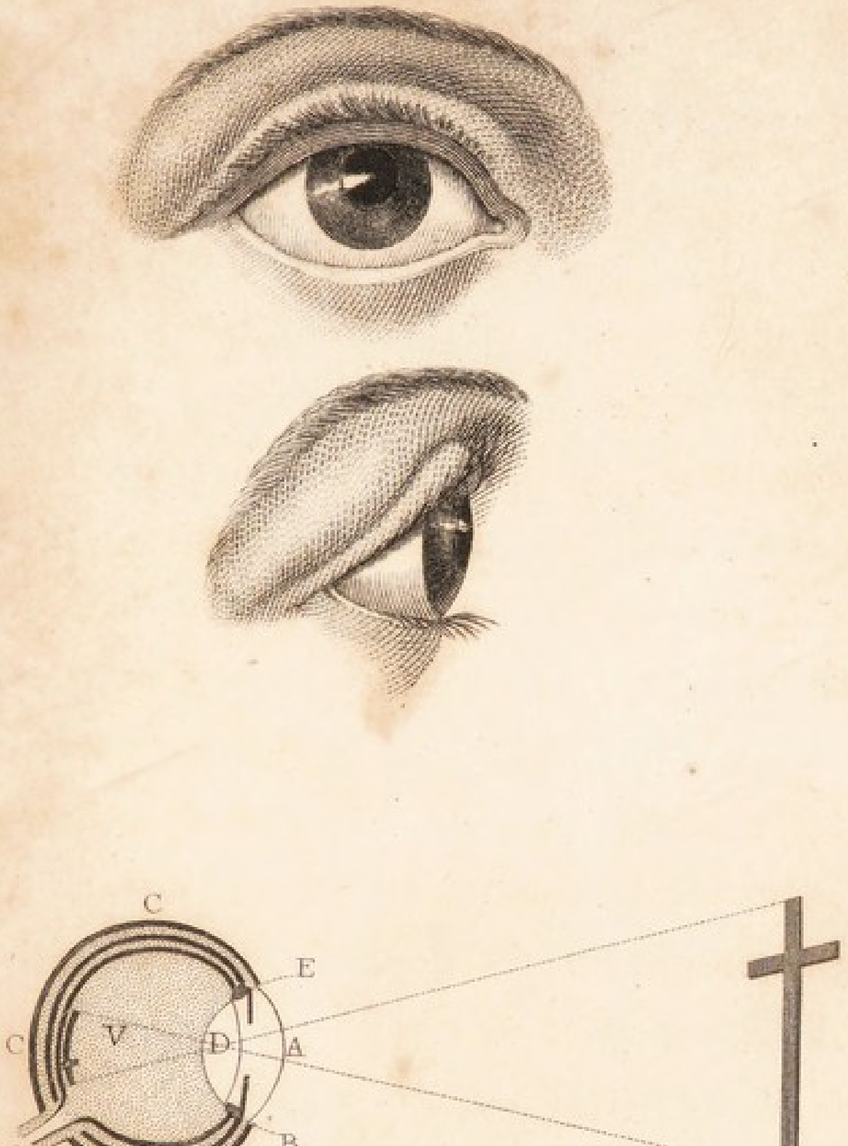
The eye is such a chamber, of a globular form, and about the size of a walnut.

In describing the different coats which compose the walls of this chamber, I shall be obliged to make use of the Greek and Latin words which have been adopted as the names of those coats, but by carefully explaining their meaning, as we proceed, I think you will not find any difficulty in understanding them.

We have here two drawings of the eye, representing, in front and in profile, that part which is visible when the eyelids are open. The figure beneath is a section of the eye, showing the internal structure, as it would appear if the eye were cut down the middle, and half of it placed before us in the same position as the profile of the eye above.

Do not perplex yourselves by attempting to understand the section at once; each line will be explained as we have occasion for it.

If you press your finger round the socket of your eye, beneath the arch of the brow, and above the cheek-bone, you will be sensible that



A *The Cornea.* CCC *The Sclerotica.*

O *The Optic Nerve.* E.B *Place of Eyelids.*

D *Crystalline Lens.* V *Vitreous Humour.*

a globular substance is concealed behind the eyelids. This is the dark chamber, the structure of which we are going to examine. It is composed of three coats or coverings, and three humours, or transparent substances, which fill the interior of the globe.

We will first speak of the coats that compose the walls of the chamber.

The outer coat is a very tough membrane; it is also *hard,* and from this property derives its name, *sclerotica,* a Greek word, expressive of hardness. It protects and supports the tender parts within it.

In the section you may suppose the upper eyelid to be situated at E, the lower at B, the opaque sclerotica surrounds the back of the eye, except where it is penetrated by the optic nerve at O, and is represented by the outer line, marked C C C: we may compare it to the shell of a walnut.

That part in front of the eye is called the cornea, from *cornu,* the Latin word for horn, which you know is a hard, transparent substance.

The cornea is the window of the eye, a *bow-window;* you see it bulges forward, projecting beyond the line that would have been formed by the regular continuation of the *sclerotica*:* we shall see the advantage of this presently.

Before we proceed any farther, I will give you some slips of card, on which the Greek and Latin names of the different parts of the eye are written, with the meaning of each affixed to it. If you at any time forget the explanation, you may then refer to your cards.

COATS OF THE EYE.

SCLEROTICA;—the *hard* outer coat.
CORNEA;—from *horn*, hard and transparent.
CHOROID;—containing a likeness.
PIGMENTUM NIGRUM;—black paint.
RETINA;—from *rete*, a net.

HUMOURS OF THE EYE.

VITREOUS;—or glassy humour.
CRYSLALLINE LENS.
AQEOUS;—or watery humour.

* Arnott, ib. 240.

Having observed the hard, outer wall of the chamber, we now come to the second coat of the eye. This is a finer membrane, or web, lining the hollow of the opaque sclerotica; it is called the *choroid,* from two Greek words, signifying, *contain* and *likeness.* The choroid contains, within the cavity which it lines, a likeness, or image, of the objects presented to the eye. Over the choroid is spread a dark pigment, adhering loosely to its hollow surface: it is called *pigmentum nigrum;* i. e. *black* paint: the use of it is to darken the chamber of the eye. This room would appear very dark and gloomy, if the walls, ceiling, and floor were painted black; but in the eye no light is useful, except that which falls upon the image, it is necessary that it should be a dark chamber.

I will take the sliding part quite out of the camera-obscura, and you will then see that the same expedient has been resorted to, in order to absorb or destroy the superfluous rays which enter through the lens. Black has not the property of reflecting light. Here is a striking resemblance, a provision made expressly for the same purpose in the eye and in the camera.

The choroid is represented by the line next to the sclerotica: we do not see it in the living eye: it is a lining extending only to the edge of the *cornea,* the bow-window in front, where it adheres to a groove in the sclerotica.*

I shall not, at present, notice that beautiful part of the eye called the *iris,* which is very dark, or blue, or hazel, or grey, in different persons. There is no part corresponding to the iris in the camera or the telescope: we will therefore speak of it afterwards.

The next object of our attention is the pupil of the eye, which appears like a black spot in the centre of the iris; but it is, in fact, the opening through which light enters the dark chamber of the eye. It corresponds with this round hole in the sliding part of the camera-obscura; and, as in the camera, there is, immediately behind that opening, a double convex lens, so also, in the eye, behind the pupil, a double convex and

* Chambers's Dict. Blumenbach, El. Physiol. 247.

most transparent substance, called the *crystalline lens,* is placed, to answer the same purpose. It converges the rays of light which pass through it from external objects, and transmits them, so as to form an image on something extended behind it, at a proper distance to receive the impression. That something in the camera is the mirror I have shown you: that something in the eye is the *retina,* which I am now about to describe.

I dare say you have often heard persons speak of their *nerves,* and of other people being *nervous.* Indeed, you have very probably heard these words employed in so vague a manner that you have no distinct meaning attached to them. This confusion may very naturally arise from the office which the nerves fulfil in the human frame: they are, while life continues, the bond of union between the body and the mind;* and are spoken of, in conversation, as sometimes belonging to the body, and forming part of its structure—sometimes as if they had

* Blumenbach, ib. 195.

reference only to the feelings of the mind. Perhaps the best way for you to have a distinct idea of the nerves, will be to compare them with another part of our frame, of which you all have some notion. I mean the blood-vessels, which proceed from the heart, like branches issuing from the trunk of a tree: these branches divide into slender sprays, or twigs; and, after distributing themselves over the body, return to the heart again. As the blood-vessels issue from the heart, so the nerves spring from the brain and spinal marrow, and spread, in minute ramifications, or branches, through the whole body. These are called nerves of motion, and correspond to the arteries issuing from the heart. If you desire to lift a book from the table, the impulse is conveyed from the brain, by the nerves of motion, to your hand. If you cut your finger, the nerves of sensation carry notice of the injury to the brain, and there excite a painful feeling. The nerves of sensation may be compared to the veins, which carry back the blood to the heart. So it goes on continually.

As there is a perpetual circulation of the blood, so there is a perpetual circulation of nervous influence. It is by means of these *feelers,* called the nerves, that we perceive what is going on in the world around us. But it is not my intention to speak further of them at present, than is necessary to give you some notion of the structure of the eye.

It is sufficient for that purpose if you think of the nerves as cords, more or less white and soft, through which impulses are conveyed to the different parts of the body, and sensations are brought back to the brain. One pair of these cords are called the optic nerves, and the globes of the eyes are fixed to them as an apple to its stalk; but with this difference, when the optic nerve has entered the dark chamber of the eye, it does not terminate like a stalk, but spreads into a membrane, or net-work, of most exquisite delicacy, which lines the back part of the eye, extending itself over the inner surface of the choroid, and forming the third coat of the eye.*

* Blumenbach, 192, 195, 247.

It is represented in the section by the innermost of these three lines, and spreads, you see, from the optic nerve at O.

It is on the fine net-work of the retina that the image of the object, to which the eye happens to be directed, is impressed: it corresponds with the mirror in the camera-obscura. Some have thought that the choroid, with its coat of black paint, is useful in rendering the image more distinct, as the silvering on the back of a mirror increases its power of reflection.* Others are of opinion that the function of the dark pigment is merely to absorb the useless light, leaving only those rays which are required to produce a distinct image.

For the image to be distinct, it is also necessary that the focus of the rays, which are refracted by passing through the crystalline lens, should fall *exactly* on the retina. When the lens becomes flattened by age, the focus is thrown farther back, beyond the retina; and wearing spectacles, with convex lenses, will as-

* Chambers.

sist the eye, and bring the focus, where it ought to be, on the retina.*

I think you will now be able to understand, on looking at this section of the eye, how the image of the cross, placed before it, is reflected on the retina.

The dotted lines represent rays proceeding from the top and the bottom of the cross to the crystalline lens marked D: (of course, other rays proceed from every intermediate part of the object; but we notice only the upper and lower rays, to avoid confusion.) You see they converge in the centre of the lens, and crossing one another, they pass out of the lens diverging, and continue to diverge, till they reach the retina, where the image is formed. You perceive that, owing to the crossing of the rays, that which proceeds from the lower part of the object falls on the upper part of the image, and there producing the reflection of the part from which it came, the image on the retina appears inverted. You may very naturally suppose

* Joyce, v. 163.

that, if the image were inverted on the retina, the object would appear to the eye to be upside-down, whereas we see men standing on their feet, and other objects in their true position. Some persons think the difficulty admits of easy explanation; but I never met with one that could be rendered quite satisfactory to you. It is, therefore, much better to leave this question for the present, and employ our thoughts on those particulars which you can distinctly understand.

We have now, I believe, considered the chief points of resemblance between the eye and the camera-obscura. We have seen that, in both, the image is formed in a dark chamber, by reflection of rays transmitted through a double convex lens. Before we examine the resemblance of the eye to a telescope, I wish to call your attention to one circumstance attending the formation of the image on the retina, which is truly wonderful. Perhaps you have seen and admired certain feats of minute penmanship, such as the Lord's Prayer written in a circle of the size of a sixpence; but what would you say to a painter, who should delineate, in a landscape of that size, all the objects that can be seen from the top of Bow Hill, with the whole sweep of the coast, from the hills of the Isle of Wight to the cliffs beyond Brighton? Yet all this multitude of objects, this wide extent of prospect, is impressed on the retina of the eye that beholds it, in correct position, form, and colour! We might also, in some situations, watch a stage-coach travelling along for half-an-hour, and be distinctly sensible of its progress, see it go up one hill and down another; yet, in all that time, the tiny image would not pass over more than one-twelfth of an inch in the minute picture painted on the retina.* Who need seek to gratify their taste for the marvellous, by reading tales of giants, fairies, or enchanters, when the wonders of our own frame are more astonishing than them all?

I will now endeavour to give you some account of the humours of the eye, which may be

* Paley, Nat. Theol. 21.

compared to the lenses of the telescope, in figure, position, and power over the rays of light. In a former Lecture, when speaking of the coloured fringes which were so great an imperfection in the early telescopes, I said that one ingenious person had fallen into the right train of thought respecting it, which led him to make a great discovery. That person was a gentleman of Essex; his name was Hall: and about the year 1729, while he was considering the difficulty, it came into his mind to inquire how this matter is managed in the eye:—then, reflecting that the humours of the eye are composed of substances which possess different powers of refraction, he thought that, if he could find substances having such powers as he supposed the humours of the eye might possess, he should be able to construct an object-glass which would be free from the coloured fringes. He accordingly made many experiments, and at length succeeded in finding the properties he desired, in two different kinds of glass. About four years after he first turned his attention to the subject, he completed several object-glasses, which showed the object in its own tints, without confusing it by the fringe of prismatic colours. They were, in fact, like Dollond's *achromatic* glasses, though Mr. Hall did not give them that name.

When ingenious men have made a discovery which is likely, from its great utility, to become a source of wealth, they frequently *take out a patent ;* that is, they obtain a writing from lawful authority, limiting the right of making the new article to themselves, for a certain specified time; and if any other persons infringe upon this right, they are liable to be punished for it in a court of justice. A patent was taken out, or requested, for making achromatic telescopes, whether by Dollond, I am not sure; but the right was disputed, and the matter brought to trial before Lord Mansfield, at Westminster Hall. From the evidence, it was clear that Mr. Hall was the inventor; but the judge remarked, that "It was not the person who locked up his invention in his desk who ought to profit by a patent for such an invention; but he who brought it forth for the benefit of the public." Whether the opinion of Lord Mansfield influenced the decision of the jury, I cannot tell you; but Dollond is generally regarded as the inventor of achromatic telescopes; and they continued to be made and sold by himself and his sons for many years. Mr. Hall was a gentleman of property, who desired no pecuniary benefit from the discovery;* therefore it seems most probable that his claim to the honour was brought forward by some instrument-maker, who wished to prevent other persons from securing a profitable manufacture to themselves.

The question of the patent is of no consequence to us; but I thought the facts would interest you, as being connected with the difficulty which led Mr. Hall to reflect on the structure of the eye, and to contrive a telescope made on the same principle.

The eye, as you may perceive from the section, is divided by the crystalline lens into two cham-

* Hutton, ib. i. 26. Paley's Nat. Theol. 15. Arnott, ii. 296.

bers. The interior and larger apartment is the camera-obscura: it is filled with a transparent substance, which, from having much the appearance of melted glass, is called the *vitreous** humour. It has also been compared to a tremulous jelly.

Next to this is the *crystalline lens*, well deserving the name by which it is distinguished; for it is beautifully clear and transparent, though more dense, or solid, than the other humours. I have heard that, when held in the hand, it feels of a tough, gluey consistence. The front of this lens is not so convex as the interior surface; and it is so represented in this section.

The remaining space, the little front chamber of the eye, between the lens and the bow-window of the cornea, is filled by a fluid, which, being perfectly limpid, is called the *aqueous* or watery humour. It is, in fact, a fluid lens, very useful in collecting the rays of light, and transmitting them through the opening called the pupil, to the crystalline lens behind it. Each of these three

* *Vitreus*, is the Latin word for glassy.

humours has some influence in refracting the rays of light, but the crystalline lens is the most powerful. Their combined effect produces an image, as you all know from experience, quite free from that prismatic fringe which was, for so many years, troublesome to astronomers.*

Having noticed the resemblances between the camera-obscura, the telescope, and the eye, we will now attend to some points in which the superiority of the eye to either of these instruments is evident, in provisions peculiar to itself, which the art of man would vainly strive to imitate.

And first, that beautiful part which immediately attracts the attention even of careless observers, on account of its motion and expression, and the variety of its colour:—the iris, which surrounds the pupil, is, you know, hazel, blue, or grey, in different individuals: it is not, however, its colour, but its office and structure that I wish you now to consider.

The office of the iris is to regulate the quantity

* Blumenbach, 249. Joyce, Sci. Dial. v. 145. 152.

of light admitted into the dark chamber of the eye, by enlarging or contracting the pupil, or opening, through which the light passes. That it may perform this service, it is furnished with two sets of fibres, one circular, the other radiating from the centre. When the circular fibres contract, the pupil is lessened: when the radiating contract, it is enlarged.* These changes take place according to the degree of light; and you may convince yourself of this, by holding a candle near the eye of one of your companions: you will then see the iris, like a curtain endued with instinct, extend its friendly screen, and, by contracting the central opening, defend the eye from the glaring light; for it is evident that less light can enter through a small opening than through one that is larger. On the contrary, if you sit for a long time in the "parlour twilight," the iris will contract its radiating fibres, and the pupil will appear very large: then, if candles are brought in suddenly, you will experience a painful sensation, till the iris

* Arnott, ib. 212.

has had time to bring the circular fibres into action, and contract the pupil so as to exclude the troublesome excess of light.*

Perhaps the terms *circular* and *radiating fibres* do not appear quite clear to you; but if you think of these fibres as threads, or strings, there will be no difficulty. If circular threads pass through the iris, round and round the pupil, when these threads contract, the circles they form will grow smaller, and the central opening will be diminished. On the other hand, when the threads, radiating or spreading from the edge of the pupil to the outside of the iris, are shortened, or contracted, is it not evident that, as the outside of the iris remains unaltered, the central opening must be enlarged, by the threads drawing the iris away from it?

The camera-obscura has nothing in its structure that can be compared with this. It must receive all the rays which fall upon the lens; while the eye, by means of its curious curtain, the iris, regulates the quantity of light admitted

* Joyce, v. 144.

to its dark chamber, without any other assistance than its own exquisite machinery.*

Another peculiarity and superiority of the eye, is its wonderful power of adapting itself to the various distances of objects which come within the limits of vision. A telescope, a microscope, a camera, must be carefully adjusted to a certain focus. Draw out the slide a quarter of an inch, more or less, and you spoil the image. Neither can a telescope present us with the image of a very near object, nor the microscope with that of a distant one; but our eyes, without any sensible adjustment or effort on our part, can examine the stamens of the flower we hold in our hand, or view the houses and plantations on the hills which bound our horizon, at the distance of six or eight miles. It is true that the eye is, to a certain extent, the creature of habit: if constantly employed in examining very near and minute objects, it will lose something of its pliancy, and be less able to observe distant things. I once heard a physician say to

* Paley, 16.

a little girl, who was bending intently over her drawing, "Do not stoop so, my dear; you will make yourself near-sighted!" On the contrary, an old sailor, whose eye has long been accustomed to gaze on the distant horizon, straining its powers to catch a view of the lifting sail, or to obtain the first glimpse of land, though he has a power of distinguishing *distant* objects, which is truly wonderful, yet he often experiences some difficulty with regard to those which are very near him.*

By what mechanism does the eye adapt itself to these varying distances? It is by the pressure of certain muscles, which, when looking at a near object, render the cornea more round and prominent: the crystalline lens beneath it is also pushed forward; and these changes vary the power of the eye over the light, so as to produce the effect that is wanted. Birds require to see both very near and distant objects, with distinctness; they are, accordingly, supplied with a further provision for altering the focus of the

* Arnott, ib. 222.

eye—a bony rim, or hoop, which, by pressure, renders it more prominent and fit for inspecting *near* objects; and a muscle which, on occasion, draws the crystalline lens back; thus suiting it for viewing many *distant* objects.

Again, in the eyes of fishes, we perceive that a greater roundness of the crystalline humour makes up for the diminished power of light, which is enfeebled by passing through the water. The convex eyes of fish are already fitted for the view of near objects: they do not want the compressing muscle, or the bony rim, to render them more prominent; but they are furnished with what they *do* want—muscles to *flatten* the eye when occasion requires it.*

In speaking of the eyes of fish, I should like to bring the real thing to your recollection. When you have partaken of mackarel, cod, or other boiled fish, you have, doubtless, observed a round, white, bead-like substance, which lies loosely in the socket of the eye, or frequently, when the fish is served by the carver, drops out

* Paley, 19. 20.

into the plate. That little globe is no other than the crystalline lens of the fish's eye: it was once a transparent jelly, but has been coagulated, or hardened, like the white of an egg, by boiling.

Compare the globular lens of the fish with the section of the crystalline lens in the human eye. What a difference! and why should this be? It is because the eye of a fish is intended to see in water, the eye of a man to see in air. If a man wished to see distinctly while his head was under water, he should put on a pair of very convex spectacles; and for this reason—the rays of light are not so easily refracted, or bent in water, as they are in air, and the converging power of a lens increases with its convexity. A small globe is the most powerfully converging of all lenses; hence it is the most suitable form for the lens of a fish's eye, which has need of great power to collect light in the water.*

Another peculiarity must be noticed. Light is not only refracted with more difficulty in

* Arnott, p. 196 and 222.

water, but its brightness is sensibly diminished. And here we cannot help admiring the minute and tender care with which the Almighty has provided for the comfort of every thing that has life, by suiting its organs to its circumstances. Surely it is a proof that he intended existence should be a blessing! How unfit, then, are any to be called His children, who do not endeavour to promote the happiness of all around them. Can the cruel, the selfish, the rebellious say, "*Our Father?*"—can they claim this connexion with Him "*whose tender mercies are over all his works?*"—or can they wilfully give pain to creatures he made to be happy, without offending Him?

The care of Providence is as much shown in withholding a contrivance that is superfluous, as in bestowing it where it is needed. Light being much feebler in water, the iris in the eyes of fish is not furnished with those fibres which contract the pupil in land animals, probably because the light they receive is never too strong for the retina.*

* Paley, 20.

The goodness of the Creator is likewise shown in the means provided for the security of this most important organ, the great inlet of our knowledge, the medium through which we study the word and the works of God; and, by silent but most expressive language, communicate to each other our joys and sorrows, our hopes and fears. How pathetically does Milton lament the privations he sustained in consequence of his blindness!

"Thee I revisit safe,
And feel thy sovran vital lamp; but thou
Revisit'st not these eyes, that roll in vain
To find thy piercing ray, and find no dawn;
So thick a drop serene hath quench'd their orbs,
Or dim suffusion veil'd———"

"Thus with the year
Seasons return, but not to me returns
Day, or the sweet approach of ev'n or morn,
Or sight of vernal bloom, or summer's rose,
Or flocks, or herds, or human face divine;
But cloud instead, and ever-during dark
Surrounds me, from the cheerful ways of men
Cut off, and for the book of knowledge fair
Presented with a universal blank
Of Nature's works to me expung'd and ras'd,
And wisdom at one entrance quite shut out."

There was, indeed, strong reason why the organ on which we thus depend for so many enjoyments, should be guarded with peculiar care: accordingly we find it lodged in a strong, deep, bony socket, where it lies imbedded in fat; it is sheltered by the eyebrows, and still better protected by the eyelid, a moveable curtain, ever ready to fall over it at a moment's warning, and always closing to secure it from danger, during sleep. To keep it moist and clean, a wash is constantly supplied, which, when it has performed its office, passes into the nose, through a hole prepared for it in the solid bone. This contrivance, like the other arrangements of the great Artificer, is only found in those animals that need it; fish, living in an element that supplies a constant lotion to preserve the moisture of the eye, are without this provision.*

The view we have now taken of the structure of the eye, slight and imperfect as it is, may yet, I hope, convince you of the infinite superiority of the works of nature, to the most ad-

* Paley, 23.

mired productions of human ingenuity. But the eye, though beautiful and important, perfect in design and execution, is still only an instrument, an *unperceiving* instrument. It is not *the eye* that *sees,* but the mind which perceives the image formed in the eye, and which may be formed there when life is extinct; if the eye of a recently killed bullock or sheep be taken out, and the opaque sclerotica carefully cut away, then, by going with it to a dark place, and turning the pupil towards any object which is brightly illuminated, you might see, through the half-transparent retina, a perfect picture of the object; the dead eye would show itself to be a complete camera-obscura.*

So far, then, as the eye is concerned, we see it to be a machine, and that we can account for the formation of the image, by causes purely mechanical—causes, which will, for a little space, continue to operate even after life has departed.

* Arnott, ii. 213.

This fact was proved to the young audience, and the structure of the eye more clearly shown, by the examination of some sheep's eyes, which were procured from the butcher, and dissected after the Lecture had been read.

Why, think you, was all this machinery requisite? Could not the Author of our being have endued us with the faculty of sight, without this apparatus of refracting lenses and reflecting mirrors? No doubt he could; but then he would have deprived us of a most striking example of his power, wisdom, and goodness. He dwells in light, which no man can approach; but it has pleased him, ever since the creation of man, to suffer his invisible perfections *to be understood by the things that he has made.* How could we *understand* them, if we were not allowed to see the manner in which they operate?

But we are permitted to see this in numberless instances, and to learn many things in another way respecting His will, and our duty. If we are reasonable creatures, we shall not shut our eyes when we may so clearly perceive that all things are ordered by his providence, and subject to his power. "Nothing, O child of reason, is without God; let Him therefore be in all thy thoughts!"

THE END.

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