

although one clause of a sentence in it, read by itself, might be supposed to do so. The passage is to be found in their work at p. 286. They begin by saying, that their experimental observations detailed in their previous pages “prove that even in a perfectly calm day there is a strong resistance to the motion of the water at the surface as well as at the bottom,” and that this resistance at the surface “is not wholly or even mainly caused by friction against the air.” They go on to say:—“One important cause of this resistance is believed to be the loss of living force, arising from upward currents or transmitted motion occasioned by irregularities at the bottom. This loss is greater at the surface than near it. The experiment of transmitted motion through a series of ivory balls illustrates this effect. It is likewise illustrated on a large scale by the collision of two trains of cars on a railway, in which case it has been observed that the cars at the head of the train are the most injured and thrown the farthest from the track; those at the end of the train are next in order of injury and disturbance; while those in the middle of the train are but little injured or disturbed. Other causes may and probably do exist, but their investigation has, fortunately, more of scientific interest than practical value. For all general purposes it may be assumed that there is a resistance at the surface, of the same order or nature as that which exists at the bottom.”

Now although this passage does contain the words “*arising from upward currents or transmitted motion occasioned by irregularities at the bottom,*” yet the illustrations, by means of the series of ivory balls, and of the collision of railway trains, show that the authors attribute to those words no clear and correct meaning, but, on the contrary, I would say they put forward quite a false view of the actions going on. Besides I myself do not admit that, except from the air, there is a resistance at the surface. According to my supposition the already resisted and retarded bottom water comes to the surface and spreads out there, but receives no new resistance there, and on the contrary receives acceleration from gravity in running down hill.

II. “The Magic Mirror of Japan.” Part I. By Professors W. E. AYRTON and JOHN PERRY, of the Imperial College of Engineering, Japan. Communicated by WILLIAM SPOTTISWOODE, Esq., M.A., Treas. R.S., &c., &c. Received October 2, 1878.

The Japanese mirror must, from three points of view, attract the notice of foreigners sojourning in that country—its prominence in the temples, the important feature it forms in the limited furniture of a Japanese household, and the wonderful property (which has apparently

created more interest in Europe than it has in Japan) possessed by certain Japanese and Chinese mirrors of apparently reflecting from their polished faces the raised characters on their backs.

It was for this third reason, the interest that such mirrors have long possessed for the student of science, that our attention was drawn to the subject, and it has been in this direction that our inquiry has been chiefly directed. The results of our investigation we propose giving in the present paper, reserving for a subsequent occasion* some remarks on the Japanese mirror as an object of worship, and the position it holds on the toilet table of a Japanese lady.

The mirror of the Far East is too well known to need an elaborate description; suffice it for the present to observe that it is generally more or less convex on the reflecting side, usually made of bronze, polished with a mercury amalgam, and having at its back a gracefully executed raised design, representing birds, flowers, dragons, a geometrical pattern, or some scene in Japanese mythical history. Occasionally there are in addition one or more Chinese characters (signifying long-life, happiness, or some similar idea) of polished metal, in bold relief. To the method of manufacture we shall refer further on, and especially to the mode in which the convexity of the surface is produced; which portion of the manufacture, while playing, as it does, an important part in the magical behaviour of the mirror, is, as far as we are aware, not to be found described in any of the Eastern or Western writings on the subject.

Just before leaving England, in 1873, the attention of one of the authors was directed to the so-called magic property of certain Eastern mirrors by the late Sir Charles Wheatstone, who explained to him that the Japanese had a clever trick of scratching a pattern on the surface of a bronze mirror which, after being polished, showed no traces of the scratches when looked at directly, but which, when used to reflect the sunlight on to a screen, revealed the pattern as a bright image. This opinion appears to have been shared by Sir David Brewster, since he says, in the "Philosophical Magazine" for December, 1832:—

"Like all other conjurors, the artist has contrived to make the observer deceive himself. The stamped figures on the back (of the mirror) are used for this purpose. The spectrum in the luminous area is *not an image of the figures on the back*. The figures are a copy of the picture which the artist has drawn on the face of the mirror, and so concealed by polishing that it is invisible in ordinary lights, and can be brought out only in the sun's rays."

As the explanation, therefore, appeared to this one of the authors to be so simple, and at the same time so complete, he practically dismissed the subject from his mind.

* A lecture at the Royal Institution.

However, he was a little astonished to find, during his residence in Japan, that, although the magic mirror was supposed in Europe to be a standard Japanese trick, and although it had been considered by Sir Charles Wheatstone as one of the best proofs of the ingenuity of the workmen of Japan, still that it formed no part of the stock-in-trade of any of the numerous conjurors in this country, and was never exposed for sale in any of the curiosity-shops. He was also still more surprised when, during the visit of the "Challenger," Sir Wyville Thomson and himself were strolling about Tokio, to find that, although they asked at several mirror shops for a mirror that showed the back, a specimen of which Sir Wyville much desired to possess, the shopkeepers seemed not to have the slightest knowledge of what was wanted. At that time the author could not but regard the total apparent ignorance displayed by the Japanese mirror-vendors on this subject as the result of his limited knowledge of the language, and he had then no notion that, in Japan at any rate, the phenomenon was the result of no clever trickery, but arose from the method in which the mirrors were prepared. We have since learnt, however, by diligent inquiry, that, as is the case with many things appertaining to Japan, so with the magic mirror, the people who know least about the subject are the Japanese themselves, and we think this only furnishes another proof that teachers to instruct the Japanese about Japan itself are the greatest *desideratum*.

Our attention was next directed to the subject of the curious property possessed by some Japanese mirrors by a letter from Professor Atkinson, of the Tokio Dai Gaku (the Imperial University), which appeared in "Nature," May 24th, 1877, and in which he says, after referring to the phenomenon of the pattern on the back being apparently reflected when sunlight is allowed to fall on the face:—

"I have since tried several mirrors, as sold in the shops, and in most cases the appearance described has been observed with more or less distinctness.*

"I have been unable to find a satisfactory explanation of this fact, but on considering the mode of manufacture I was led to suppose that the pressure to which the mirror was subjected during polishing, and which is greatest on the parts in relief, was concerned in the production of the figures. On putting this to the test by rubbing the back of the mirror with a blunt-pointed instrument, and permitting the rays of the sun to be reflected from the front surface, a bright line appeared in the image corresponding to the position of the part rubbed. This experiment is quite easy to repeat, a scratch with a knife, or with any other hard body, is sufficient. It would seem as if the pressure upon the back during polishing caused some change in

* Only a *small* percentage, however, of the total number of Japanese mirrors that the authors of this paper have experimented on show the phenomenon clearly.

the reflecting surface corresponding to the raised parts, whereby the amount of light reflected was greater; or supposing that, of the light which falls upon the surface, a part is absorbed and the rest reflected, those parts corresponding to the raised portions on the back are altered by the pressure in such a way that less is absorbed, and therefore a bright image appears."

Professor Atkinson cautiously adds: "This, of course, is not an explanation of the phenomenon, but I put it forward as perhaps indicating the direction in which a true explanation may be looked for."

In vol. i, p. 242, year 1832, of the "Journal of the Asiatic Society of Bengal," Mr. Prinsep gives an account of a Japanese magic mirror which he had seen in Calcutta. He does not appear to have made any direct experiments with this mirror for the purpose of elucidating which of all the possible causes is the real cause of the magic phenomena, but rather he concludes "from analogy that the thin parts or tympanum of the Japanese mirror are slightly convex with reference to the rest of the reflecting surface, which may have been caused either by the ornamental work having been stamped or partially carved with a hammer and chisel on its back; or, which is more probable, that part of the metal was by this stamping rendered in a degree harder than the rest, so that in polishing it was not worn away to the same extent." It does not seem to have occurred to him that Japanese mirrors are *cast* and *not stamped at all*.

In "Nature," June 14th, 1877, Mr. Highley refers to the exhibition of a Japanese mirror by Professor Pepper some years ago at the Polytechnic Institution, London, and to the praiseworthy attempt of an English brass worker, who saw the experiment, and who also was under the false impression that such mirrors were stamped, to solve the problem. "The workman found that taking ordinary brass and stamping upon its surface with any suitable die, not once, but three times in succession, upon exactly the same spot, grinding down and polishing between each act of stamping, a molecular difference was established between the stamped and unstamped parts, so that images of the pattern could be reflected from the finally polished surface, just as with the Japanese specula, though no difference of surface could be detected with the eye."

To people who have not been in China or Japan, and personally studied mirror-making, this idea of stamping seems very plausible, for Sir David Brewster, on p. 113 *et seq.* of his "Letters on Natural Magic," published in 1842, describes fully a method, depending on the molecular change produced by stamping, by means of which the inscriptions on old coins, that have been worn quite smooth, may be deciphered. This method merely consists in heating the coin on a piece of red-hot iron, when the inscription becomes visible from the different rate of oxidation of the part of the coin that has been subjected to great

pressure in stamping from that part that has been subjected to less. But, as already mentioned, all explanations depending on stamping must at the outset be put on one side when studying the behaviour of Japanese mirrors, since casting, and not stamping, is the process employed in their manufacture.

In the "Reader" (a paper now extinct) for February, 1866, Mr. Parnell attempts to explain the phenomenon by an inequality in the surface of the mirror, produced by the thinner portion warping more in cooling than the thicker part where the pattern exists, and he endeavours to experimentally examine this by studying the direct reflection of the globe of a gas-lamp, as seen in the different parts of the mirror. We, as well as Professor Atkinson, have tried to repeat this experiment with some magic mirrors in our possession, but we cannot say that it affords any conclusive evidence regarding the cause of the phenomenon.

It therefore appeared to us a year ago that the subject would repay investigation, an opinion also expressed by Professor Silvanus Thompson, who, in writing from University College, Bristol, to "Nature," during June of 1877, suggested that the Japanese mirrors exhibited at the Loan Collection of Scientific Apparatus in London might, if they showed the phenomenon, be used for such an investigation. And as Professor Atkinson did not propose following up the question himself, he lent us the mirror which he possessed, and cordially agreed with our proposal that we should undertake the investigation. This we have done, and obtained the results which we venture to submit this evening to the Society.

At the commencement of the inquiry we naturally desired to see what had been written on the subject of Japanese mirrors, and this brought to our notice the information regarding mirrors generally in this country, which, as mentioned at the beginning of this paper, will form, we propose, the substance of a subsequent communication. But, of the *magic mirror*, Japanese literature (so far as we have been able to ascertain) makes absolutely no mention.

In "Les Industries Anciennes et Modernes de l'Empire Chinois," published in 1869, by MM. Stanislas Julien and Paul Champion, there is a short article on "Les Miroirs Magiques des Chinois, et leur fabrication," taken from the paper communicated by M. Julien to the French Academy of Sciences. In this he says:—

"Many famous philosophers have for a long time, but without success, endeavoured to find out the true cause of the phenomenon which has caused certain metallic mirrors constructed in China to have acquired the name of *magic mirrors*. Even in the country itself where they are made no European has, up to the present time, been able to obtain either from the manufacturers, or from men of letters, the information, which is so full of interest to us, because the former keep

it a secret when by chance they possess it, and the latter generally ignore the subject altogether. I had found many times in Chinese books details regarding this kind of mirrors, but it was not of a nature to satisfy the very proper curiosity of philosophers, because sometimes the author gave on his own responsibility an explanation that he had guessed at, and sometimes he confessed in good faith that this curious property is the result of an artifice in the manufacture, the monopoly of which certain skilled workmen reserve to themselves. One can easily understand this prudent reticence when we remember that the rare mirrors which show this phenomenon sell from ten to twenty times as dear as the rest."

M. Julien then gives an elaborate description of one of these mirrors in the possession of the Marquis de La Grange. He further remarks that such mirrors are called in Chinese *theou-kouang-kién*, which means literally "mirrors that let the light pass through them," and that this name has arisen from a popular error on the subject. Chin-kouo, a Chinese writer who flourished in the middle of the eleventh century, speaks with admiration about them in his memoirs called *Mong-ki-pi-tân*, book xix, folio 5. The poet Kin-ma has celebrated them in verse; but up to the time of the Mongolian emperors nobody could explain the cause of the wonderful phenomenon. Ou-tseu-hing, who lived between 1260 and 1341 under this dynasty, had the honour of being the first to throw any light on the subject. He says:

"When we turn one of the mirrors with its face to the sun, and allow it to throw a reflection on a wall close by, we see the ornaments or the characters which exist in relief on the back appear clearly. Now the cause of this phenomenon arises from the employment of two kinds of copper of unequal density. If on the back of the mirror a dragon has been produced while casting it in the mould, then an exactly similar dragon is deeply engraved on the face of the disk. Afterwards the deep chisel-cuts are filled up with denser copper, which is incorporated with the body of the mirror, which ought to be of finer copper, by submitting the whole to the action of fire, then the face is planed and prepared, and a thin layer of lead or of tin spread over it.*

"When a beam of sunlight is allowed to fall on a polished mirror prepared in this way, and the image is reflected on a wall, bright and dark tints are distinctly seen, the former produced by the purer copper, and the latter by the parts in which the denser copper is inlaid."

If, then, we understand this description of Ou-tseu-hing correctly, it would appear that the pattern appears by reflection as a dark image on a bright ground, the opposite of what is experienced in Japanese mirrors.

* This probably refers to the mercury amalgam which is used in polishing, and which Ou-tseu-hing mistook for lead or tin.

Ou-tseu-hing adds that he has seen a mirror of this kind broken into pieces, and that he has thus ascertained for himself the truth of this explanation.

In a recent interesting article published in No. 29 of the "Gartenlaube," Heft 8, 1877, by the well-known German popular writer whose *nom-de-plume* is Carus Sterne, doubt is thrown on the above explanation, since Herr Sterne thinks the magic mirror he himself possesses is too thin for any such inlaying to have been performed. In quoting the information given by M. Julien, to which reference is made above, he incidentally mentions that it is taken from the fifty-sixth volume of the Chinese encyclopædia called "*Ke-chi-king-youen*." Herr Sterne adds that these magic mirrors were known to the Chinese from the earliest times, and that one of their writers spoke about them in the ninth century of the Christian era. He remarks that the Roman writer Aulus Gellius, who lived seventeen centuries ago, referred to mirrors that sometimes reflected their backs and sometimes did not. From the great antiquity of the Chinese magic mirrors Herr Sterne thinks it probable that the mirrors with secret signs and figures of imps on the back which formed a portion of the stock-in-trade of the witches of the middle ages were of Eastern manufacture. He further alludes to the account given by the Italian historian Muratori of the magic mirror found under the pillow of the Bishop of Verona, who was afterwards condemned to death by Martin della Scala, as well as to the one discovered in the house of Cola da Rienzi, on the back of which was the word "Fiorone."

Neither in "Les Memoires concernant les Chinois par les Missionnaires," nor in Duhalde's classical work on China, is there any mention of the magic mirror. I understand, however, that a short paper on the subject, by Professor Harting, appeared some years ago in a Dutch periodical, the "Album der Naturer;" this I have not seen: but Dr. Geerts, a Dutch gentleman resident in Japan, and who has a most extensive acquaintance with the literature bearing on that country, informs me no explanation of the phenomenon was contained in that article.

Japanese literature, as already mentioned, appears to be quite barren of information regarding their own or the Chinese mirrors which appear to reflect their backs. But in the *shim-pen-kamakura-shi*, or "New Collection of Writings about Kamakura," it is mentioned that in the temple *Kenchoji*, situated in the ancient capital of the Shogun,* there is treasured up a wonderful old mirror, $3\frac{1}{2}$ sūns high and 3 sūns wide,† which, when looked at somewhat obliquely, shows the image of

* Shogun, the military usurper of the throne of Japan, and recognized in modern times prior to the revolution of 1869 as the rightful sovereign. He was sometimes erroneously called the Tyeoon.

† A *sūn* is nearly one and one-fifth of an inch.

a Buddhist god. This appearance, however, is in no way connected with the pattern at the back, which consists of a new moon reflected in the sea; the artistic balance of the picture being maintained by a rosary and a plum tree. The hole in the upper portion of the mirror is probably for the attachment of a silk cord to hang it up by. The supposed marvellous character of this mirror causes great reverence to be shown to the god of the temple, as it is considered to furnish an undoubted proof of his supernatural character; in fact, the mirror receives nearly as much respect as this Buddhist deity himself.

The way in which the optical effect has been produced is said to be the same as that described in the *Kokon-i-to*, "The Genealogy of the Old and New Physicians," and which is as follows:—Take ten parts of shio (gamboge), one of funso, and one of hosha (borax). Powder these thoroughly, and mix them to the consistency of a paste with a little dilute glue. If any pattern be drawn on the surface of the mirror with this paste, and then allowed to dry, the pattern will be seen, even after polishing, if looked at obliquely.

A mirror, in the face of which was seen the appearance of the famous priest, Shinran-sho-nin, who instituted the Shinshiu religion, to which the Honguangi temples at Kioto belong, was formerly in the possession of the Kuge* Rokujo, and was, to a certain extent, worshipped. Wood-cuts of this mirror were also sold at this nobleman's house, and were regarded as a faithful representation of the priest Shinran-sho-nin. One of the persons formerly employed at the Honguangi temples, Kioto, tells us he remembers, some years ago, a messenger, coming from Mr. Rokujo, asking that the authorities of the temple would give a certificate, stating that the mirror had been constructed by Shinran-sho-nin himself for holy purposes. This, however, they declined to do, believing rather that Mr. Rokujo had fabricated it himself to obtain money on exhibition. Mr. Rokujo, to whom we have applied on the subject, says, that the old tradition in his family was that the mirror originally came from Echigo;† also that, after the failure to obtain a certificate of its sanctity referred to above, he sold it to a temple situated near Kioto, from which, however, it was subsequently removed, and that he is quite unacquainted with its present whereabouts.

A Tokio‡ mirror maker, however, tells us that he has seen an exactly similar mirror at Okasaki-mura, a small village near Kioto, so perhaps this is the present habitation of Mr. Rokujo's old mirror.

It does not appear that this chemical method of preparing the face

* "Kuge," a nobleman formerly attached to the Micado's Court at Kioto, the ancient capital.

† Echigo, a province in the centre of Japan.

‡ "The Eastern Capital," the name given to Yedo since the revolution of 1869 when the Micado transferred his court there from Kioto.

has ever been employed in Japan to alter a portion of the surface in such a way that this part becomes visible in the image formed by reflection, although invisible when looked at directly. A certain Tokio mirror maker, however, said that he had employed the chemical method for this purpose in the following way:—

Coat the surface of the mirror with *urushi* (Japanese varnish), with the exception of the portion that it is desired shall cast the brighter reflection, then act on this part with a paste composed of equal parts of sulphur and copper sulphate, powdered and mixed with *shiro-umedzu* (white plum acid). If this paste, after being allowed to dry on the mirror, which takes about two days, be rubbed off, and the mirror be frequently polished, the pattern (so said this mirror maker) will become invisible when looked at, but will appear in the reflection of the mirror thrown on to a screen. If the above be true, then, if a pattern be drawn on the face of the mirror with the varnish while the remainder of the face is acted on chemically, this pattern should, on reflection, appear darker than the rest. We therefore instructed him to prepare two mirrors, and on the face of one to act chemically on a portion corresponding with the letter “C,” while, with respect to the other, he was to leave untouched only a small part of the face, corresponding with the letter “N.” This he did; after several polishings of the two mirrors both letters could be seen, either directly or on reflection; after many polishings, however, the letter “C” disappeared for direct vision, but it also disappeared for reflection, and the letter “N” remained visible, either if looked at very obliquely, or when a bright light was reflected on to a screen. In other words, the attempt of this mirror maker turned out a failure. He regards it as resulting from a loss of his former skill, but we are inclined to think that he was confusing the method with which he was acquainted for making an image visible when the face of the mirror is looked at obliquely (the phenomenon which is observed in the mirror at Kamakura), with a method for making the so-called magic mirror, of which he has probably no knowledge. One very interesting fact, however, came out in this experiment, and that was the mirror on which the letter “C” was made, and which did not originally reflect the pattern on the back, acquired the power to do so after *ten* successive polishings. In fact, the mirror maker caused this mirror to acquire the so-called magic character, but in a way unexpected by himself.

Explanations:—The possible explanations of the phenomenon shown by certain Japanese mirrors may be divided into three classes:—

1. The pattern might be scratched on the face of the mirror and hidden by subsequent polishing.

2. The portion of the face corresponding with the pattern might have a different molecular constitution from the metal forming the remainder of the mirror.

This difference in molecular constitution might produce the results:—

a. By causing the portion of the face corresponding with the pattern at the back to attract more mercury, and so to become capable of being polished more easily; or

b. By causing it to be harder, and so to acquire a better polish; or

c. By causing it to polarise light.

This difference in molecular constitution might be produced:—

a. By the inlaying of another metal; or

b. By portions of the surface being acted on chemically; or

c. By unequal density produced by inequality in the rate of cooling; but

d. *Not* by stamping, Japanese mirrors being all cast.

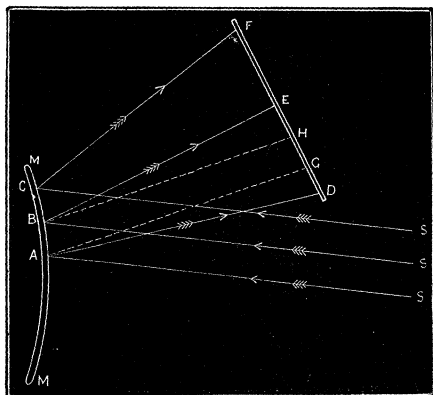
3. The phenomenon might arise from the face of the mirror having intentional or accidental inequalities on its surface, in consequence of which, the part corresponding with the pattern on the back might be relatively concave, and so concentrate the light, or, at any rate, might disperse it less than the remainder of the slightly convex mirror.

The question then resolves itself into considering to which of these three groups of causes is the apparent reflection of the back in some Japanese mirrors due.

To ascertain this, we tried Sir David Brewster's suggestion that the light reflected by the thicker part of the mirror was polarised; but even with a fairly good polariscope, we could detect no marked difference between the light reflected from the various portions of the surface. This failing, we availed ourselves of a very simple method of experimenting, but one that has apparently not suggested itself to previous observers. On one occasion, when some of our students were using lenses to endeavour to make the exhibition of the phenomenon more striking, it occurred to us that the employment of beams of light of different degrees of convergence or divergence would furnish a test for deciding the cause of the whole action. For while, if the phenomenon were due to molecular differences in the surface, the effect would be practically independent of the amount of convergence of the beam of light; on the other hand, if it were due to portions of the reflecting surface being less convex than the remainder, a complete *inversion* of the phenomenon might be expected to occur, if the experiment, instead of being tried in ordinary sunlight, were made under certain conditions in a converging beam—that is, the thicker portions of the mirror might be expected to appear darker instead of brighter than the remainder. Figs. 1—5, which are all much exaggerated for the sake of distinctness, explain this better. MM, fig. 1, represents an ordinary Japanese slightly convex polished bronze mirror. SA, SB, SC, are rays of a parallel beam of light falling on it, and reflected as AD, BE, CF, on to a screen DF; then, if the areas

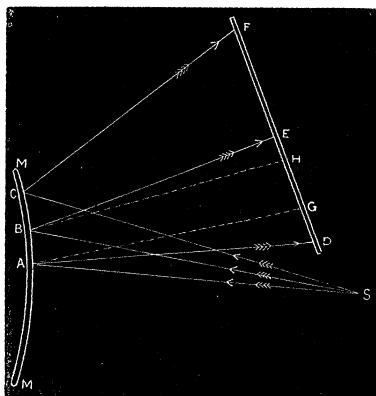
AB and BC of the mirror be about equal to one another, the amount of light falling on them will also be equal ; and, since the illuminated areas DE and EF are about equal, they will be equally bright. But if

FIG. 1.



a portion AB of the mirror be, for any reason, flatter than the remainder, then the quantity of light which falls on it, instead of being reflected so as to illuminate the area DE of the screen, will only illuminate some such area as GH. Now, this area being smaller than EF, but receiving the same quantity of light, will appear much brighter than EF ; in addition, too, the spaces DG and HE receive but very

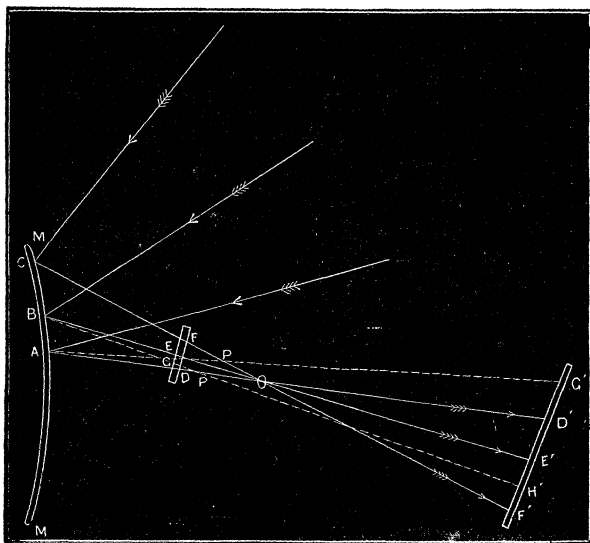
FIG. 2.



little light, and are consequently relatively dark, the excess of brightness, therefore, of the area GH will be apparently much heightened by contrast. And exactly the same reasoning applies to fig. 2, in which the mirror is illuminated by a beam of light diverging from

the point S. But if we now turn to fig. 3, where the light is converging to a point behind the convex surface, and nearer to the surface than half the radius of the mirror, then, after reflection, the light converges to a point O in front of the mirror, and, as before, the area GH (which has become almost a point, G) is smaller, and therefore brighter, than the area DE, as long as the screen is nearer to the mirror than the point P, but larger, and therefore darker, than D'E', when the screen is farther from the mirror than P. In other words, if the phenomenon of the Japanese mirror is due to the curvature of different parts of the surface being slightly different, then with the arrange-

FIG. 3.



ment of light shown in fig. 3, the whole effect ought to undergo an *inversion* as the screen passes through P; that is to say, if the parts corresponding with the pattern at the back are the flatter, then, while these should appear as bright on a dark ground when the screen is at a position DF, they ought to appear as dark on a bright ground when the screen is at a position D'E'. Now this is exactly what is found to be the case when tested experimentally.

Again, if the phenomenon is, as the previous experiment would lead us to conclude, due not to unequal reflecting power of the different portions of the surface of the mirror, but to minute inequalities on the surface, in consequence of which there is more scattering of the rays of light falling on one portion than on another, then since rays of light making very small angles with one another do not separate perceptibly until they have gone some distance, it follows, that if the

screen be held *very near* to the mirror, the apparent reflection of the back, the magical property in fact, ought to become invisible. And this, also, is exactly what happens when we make the screen almost touch the polished surface.

We have, therefore, strong reasons for favouring the "inequality of curvature" theory. In order, however, to make the explanation quite certain, we have had made a small concavity and a small convexity on the face of one of the mirrors, by hammering with a blunt tool, carefully protected with a soft cushion to avoid scratching the polished surface, and, as is seen on trying the experiment, the concavity reflects a bright image and the convexity a dark one when the screen is in the position DF, but when the screen is shifted to D'F', it is the convexity which appears as the bright spot, and the concavity as the dark one.

And not only do we think that the thicker portions of the convex mirror are flatter than the remainder, but the existence of a focus for a divergent pencil (as evidenced by a best position of the screen in fig. 2) leads to the conclusion that, in some instances at any rate, the thicker portion is actually *concave*, and is found to have a radius of about three to four metres.

In the account of the Chinese Magic mirror, given by Ou-tseu-hing at the end of the thirteenth century, he mentions that the wall or screen on which the shadow is cast should be *near*, an instruction which people have usually found it necessary to follow in order to see the phenomenon clearly. But this condition of proximity of the screen to the mirror is necessary, simply because the sunlight falling on the mirror neither forms a parallel beam, nor one diverging from, nor converging to, a single point, but consists, of course, of an enormous number of slightly diverging beams. Consequently, on any *one* point of the mirror there fall rays of light, each making a slightly different angle with the surface. Now, as these, after reflection, proceed in slightly different directions, they will illuminate different points of the screen, and, therefore, make a well-defined image impossible, unless the screen be held near. If ordinary sunlight then be employed, the screen, as previously explained, must be held *not so near* the mirror that the inequalities of the surface are unable to produce any decided displacement of the rays before they strike the screen, and in addition, as we now see, *not so far* from the mirror that the different rays falling on the *same* point are perceptibly separated before they reach the screen; or, putting the above conditions into more precise mathematical language, the screen must not be held so near the mirror that the product of this distance into the angle between the normals to two adjacent parts of the surface is too small, and not so far from the mirror that the product of this distance into the angular diameter of the sun is too large.

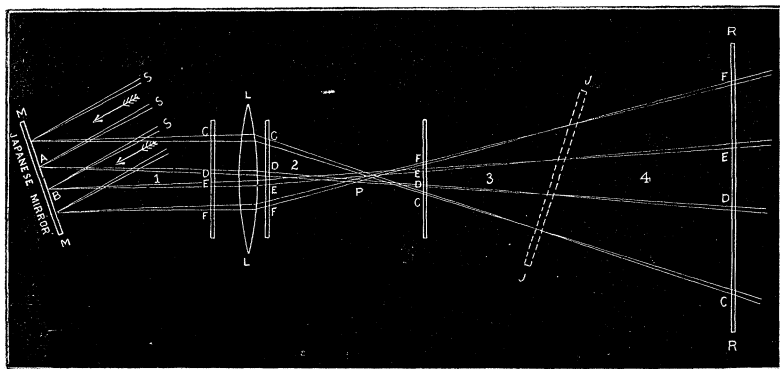
This condition, however, of proximity of the screen to the mirror ceases to have any weight, and the phenomenon can be shown to a large audience by projecting it on a distant wall if one or other of the following devices be adopted :—

1. Allow the sunlight to first pass through a small hole, so that all the rays falling on the same point of the surface of the mirror make the same angle with the surface.

2. Obtain the same result thus :—first let the sunlight fall on a convex lens or on a concave mirror which brings it to a focus, and afterwards causes it to diverge from a single point, then hold the Japanese mirror in the diverging beam at about eight or more feet from the principal focus of the lens or auxiliary concave mirror.

3. Illuminate the mirror with light diverging from a single bright-point at some distance, as, for example, from an electric light at the other end of the room, the screen, of course, being shaded from the direct light of the lamp.

FIG. 4.



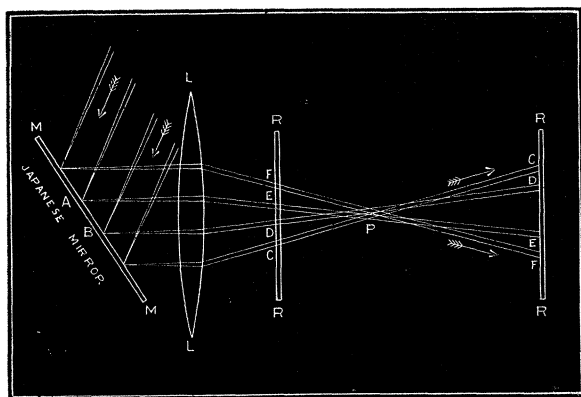
4. Allow the sun's rays to fall on the nearly plane Japanese mirror MM, and after reflection let them pass through a converging lens so adjusted that the screen RR, fig. 4, is beyond the principal focus, P, of the mirror and lens combined, and also beyond JJ, the conjugate focus of the mirror, that is the place at which the image of the Japanese mirror is formed by the lens.

The last method causes the effect to be better than that obtained with ordinary sunlight alone, because the insertion of the lens separates the rays falling on different points of the Japanese mirror more than it separates those which, coming from different points of the sun, are reflected in different directions by the same small portion of the Japanese mirror. In fact, the employment of the lens corrects, to a certain extent, the blurring of the image produced by the sun not being a single luminous point. Number 4 method also economises

the light best, and if the screen is distant, may be employed to produce a large figure of the pattern on the back of the mirror, but the result is not nearly as beautiful as that obtained by either of the former three methods, the first two in particular of which, if the mirror is placed in a darkened room, at about fourteen feet distance from the luminous point produced by a tropical sun, cause the reflection on the wall to assume an appearance startling even to an educated mind, and which might well have brought to the feet of the magician the ignorant poor of the middle ages.

Referring to the arrangement of mirror and lens shown in fig. 4, and remembering the reasoning employed in the case of figs. 1, 2, and 3, we should conclude that if a portion, AB, of the mirror is more concave than the rest, this portion ought to appear as bright on a dark ground if the screen be held in the positions 1, 2, or 4, since, in all these, DE is less than CD or EF, but if it be held at any point, 3 in the region between the principal focus P and JJ, then, since here DE is greater than CD or EF, the concave portion ought to appear as dark on a relatively light ground, while at JJ, the image being uniformly illuminated, the appearance of the pattern ought to disappear altogether. We should expect, then, that the passage of the screen, either through P or through JJ, ought to produce an inversion of the phenomenon if the theory that we are here advocating of the Japanese mirror be correct.

FIG. 5.



Again, imagine the lens LL to gradually move up to the mirror until it attains a very near position, as in fig. 5, then an inspection of the direction of the rays shows that any concave part, AB, of the mirror must appear on the screen as light on a dark ground for all points between the lens and the principal focus P, but that it will be seen as dark on a relatively light ground for all positions of the screen

in the region beyond P. On arranging the light as in fig. 4, and placing the screen successively in the positions 1, 2, 3, JJ, and 4, afterwards moving the lens up to the Japanese mirror, until the distance between it and the mirror was less than the focal length of the lens, we found that the experiments bore out, in every detail, the results that must follow from the "inequality of curvature theory."

Returning now to fig. 3, in which it was first shown that a converging beam produced an inversion of the phenomenon, we find it impossible to obtain a distinct dark image of the pattern on a light ground by the employment of one converging lens only. This is partly due to the fact that here we are dealing with diverging pencils of light falling on the screen, so that no true image of the pattern is formed; and partly caused by the blurring effect arising from a beam of sunlight, consisting of a number of slightly diverging pencils. This latter may be, to a certain extent, corrected, either by allowing a very small beam of sunlight to fall on the single converging lens, or by causing the sunlight to be brought first to a focus by one lens, and then with a second lens at several feet distance, forming another convergent pencil of light, in which the convergent mirror is placed.

Guided by all that proceeds, we are led to the undoubted conclusion, that the third of the proposed explanations is the correct one, namely, that the whole action of the magic mirror arises from the thicker portions being flatter than the remaining convex surface, and even being sometimes actually concave.

The next question arises, why is there this difference in the curvature of the different portions of the surface? The experience that one gains from an examination of a large number of Japanese mirrors supplies, in part at any rate, the answer to the question. No thick mirror reflects the pattern on the back, not one of the many beautiful mirrors exhibited at the National Exhibition of Japan in 1877, and which we were so fortunate as to be able to experiment with in a darkened room with a bright luminous point at some twelve feet distance, shows the phenomenon in the slightest degree; some good old mirrors in the museum of the Imperial College of Engineering, and which belonged to the family of the late Emperor, the Shogun, of Japan, fail to reflect any trace of a design, and some old round mirrors without handles, which we have also tried, are, with the exception of one about six inches in radius, and for which the owner asked many pounds, equally unsuccessful. Now this in itself, independently of the erroneous idea regarding stamping, is almost sufficient to negative Mr. Prinsep's idea "that part of the metal was by this stamping rendered in a degree harder than the rest, so that in polishing it was not worn away to the same extent." Again, it is not that the pattern is less clearly executed on the backs of these choice mirrors, since the better

the mirror the finer and bolder is the pattern, but what is especially noticeable is that every one of these mirrors is as a whole far thicker than an ordinary Japanese mirror, and its surface is much *less convex*. This naturally led us to inquire, how are Japanese mirrors made convex? are they cast so, or do they acquire this shape from some subsequent process? In the article "Miroirs" in "Les Industries Anciennes et Modernes de l'Empire Chinois," nothing is said on this point, and the paper communicated by M. Julien on the Chinese Magic Mirror to the French Academy, is equally silent on this subject. Professor Pepper says, "Are the mirrors cast in a double mould one side of which is in *intaglio* and one side in *relievo*?" but has no information by which he can answer this question. We also were quite unable to gain any assistance from foreign or from Japanese books or manuscripts regarding the method by which the convexity observed in almost all Japanese mirrors is produced, and were consequently compelled to make inquiries ourselves among mirror makers. Now although shops where mirrors are sold are common enough in Tokio, workshops where they are made are very difficult to find. A workshop was said to exist at Oji, but after a long search in this suburb of Tokio we found only one old woman and a little mercury amalgam in a small hovel about six feet by four, as the representative of the mirror industry. As women are supposed to know nothing in Japan, it was useless to make inquiries of her: another search made on a subsequent occasion in a different direction only elicited the information that mirrors were not made at that time of the year, as the moulds were frost-bitten. Mirror-sellers, mirror-polishers we could find, but nobody in Tokio seemed to cast mirrors. We have since found out that this is really the case, since all the common mirrors come from the ancient capital Kioto, about 400 miles to the south of Tokio, and it is only when some special order is given that mirrors are made in the capital. However, at last we lighted on some mirror makers and sellers combined, from whom Mr. Kawaguchi (one of the assistants to the Professor of Natural Philosophy at our College), in the course of many conversations, extracted much valuable information. As a large portion of this is not to be found, as far as we aware, in any books, and as it bears upon the explanation of the magic mirror given in this paper, it naturally finds a place here.

Composition used in Making Mirrors.—In regard to the composition of the mirrors the following seems to be the metal-mixture employed in Tokio:—

Mirrors of First Quality.

Copper	75·2 parts.
Tin.	22·6 ,,
Iyo shirome	2·2 ,,

Mirrors of Second Quality.

Copper	81·3 parts.
Tin.....	16·3 „
Iyo shirome	2·4 „

Mirrors of Third Quality.

Copper	87·0 parts.
Tin.....	8·7 „
Iyo shirome	4·3 „

Mirrors of Fourth Quality.

Copper	81·3 parts.
Tori shirome.....	16·3 „
Iyo shirome	2·4 „

Mirrors of Fifth Quality.

Copper	71·5 parts.
Tori shirome.....	28·5 „

Iyo shirome is the name given to a natural sulphide of lead and antimony taken out of the impurities of the lead ore from the mines of the province Iyo, in the island Shikoku. *Tori shirome* is a shirome containing an admixture of copper. In vol. iv of the "Transactions of the Asiatic Society of Japan," Dr. Geerts gives the metal-mixture employed in one of the largest mirror foundries in Kioto as follows:—

Mirrors of First Quality.

Lead	5 parts.
Tin	15 „
Copper.....	80 „

Mirrors of Inferior Quality.

Lead	10 parts.
Shirome	10 „
Copper.....	80 „

MM. Champion and Pellet give as the result of their analysis of the material of Chinese mirrors:—

Copper	50·8 parts.
Tin.....	16·5 „
Zinc	30·5 „
Lead	2·2 „

One of the chief of the Tokio mirror makers tells us he never puts ordinary lead into the mixture, since he finds this makes the face of

the mirror very difficult to be amalgamated ; also that, in casting, the lead comes to the surface and spoils the mixture. Zinc he also finds has the same effect. But as a small amount of lead is required to be inserted in the composition to prevent the metal from becoming too brittle, the shirome or sulphide of lead and antimony is employed. The chief sources of this shirome arranged in order of merit are the provinces in the south of Japan, called—

1. Iyo, in the island Skikoku,
2. Shekishu,
3. Choshu,
4. Tosa, in the island Shikoku,

but the *shirome* coming from the last province, Tosa, cannot be used for mirrors, as it contains too much lead.

The mirrors of the first quality are only manufactured on receipt of a special order, and new mirrors of even the second and third qualities are rarely found ready made. The ordinary stock of the shops consists of mirrors of the fourth quality, in which there is no tin. The absence of both tin and the Iyo shirome in the composition of the fifth quality is found to make the mirrors give a pale reflection, from the difficulty of amalgamation, and so the fifth composition is not often used.

The composition for the common mirrors is made at the copper mines and forwarded to the various mirror foundries. Formerly the metal for mirrors was extensively prepared at Kioto, but the trade is dying out now, and is said to have been slowly diminishing for the last hundred and thirty years, at the commencement of which period it had reached its maximum.

Moulds for Mirrors.—The most striking feature of the moulds is that *while practically all Japanese mirrors are convex, the surface of each half of the mould is quite flat.* The material used for making the mould is a mixture of a special kind of clay (found near Tokio and Osaka) with water and straw-ash. Two suitable slabs having been formed from this plastic compound with the aid of wooden frames, a thick layer of half liquid mixture of powdered old crucibles, or of a fine powder called *to-no-ko*, made from a soft kind of whetstone, is spread on them. The design for the back of the mirror is then cut directly on one half of the mould, or a sketch drawn on paper is first stuck on and used as a guide in cutting the design in the clay. Sometimes, but rarely, the design is stamped in the clay with a pattern wood-block cut in relief like the proposed back of the mirror. After the design is complete a rim of the same material as that used in the construction of the mould, and having a thickness equal to that desired for the mirror, is attached to one half of the mould. The two halves are then dried in the smoke of a pine tree fire, pressed and tied together, and laid in the casting

box at an angle of 80° with the horizon, the half of the mould on which the design has been cut being uppermost. Finally, the molten speculum metal is run into a number of moulds at the same time, which, when cold, are broken up and the castings removed.

Mirrors cast in a mould, in which the design has been cut by hand, are called *ichi mai buki*, "mould used once," and are regarded as "artists' proofs," as the design on the back is well defined. To form subsequent moulds the two halves are pressed, when the clay is wet, on an *ichi mai buki* mirror, and the pattern is this way transferred, but the designs on the backs of the mirrors cast in such moulds are not as clear as on an *ichi mai buki* mirror, which therefore sells for a much higher price.

Curving the Surface.—The rough mirror is first scraped approximately smooth with a hand-scraping tool, and as this would remove any small amount of convexity, had such been imparted to it in casting, it is useless to make the mould slightly convex. If, however, a convex or concave mirror of small radius is required, then the surface of the mould is made concave or convex. On the other hand, to produce the small amount of convexity which is possessed by ordinary Japanese mirrors the following method is employed, if the mirror is thin, and it is with thin mirrors we have especially to deal, since it is only in these mirrors that the apparent reflection of the back is observed. The mirror is placed face uppermost flat on a wooden board, and then scraped or rather scratched with a rounded iron rod about half an inch in diameter and a foot long, called a *megebo*, "distorting rod," so that a series of parallel scratches is produced, which causes the face of the mirror to become convex in the direction at right angles to the scratches, but to remain straight parallel to the scratches, in fact it becomes very slightly cylindrical, the axis of the cylinder being parallel to the scratches. This effect is very clearly seen by applying a straight-edge in different ways to the face of an unpolished mirror which has received a single set of scratches only. A series of scratches is next made with the *megebo* in a direction of right angles to the former, a third set intermediate between the two former, and so on, the mirror each time becoming slightly cylindrical, the axis of the cylinder in each case being parallel to the line of scratches, so that eventually the mirror becomes generally convex. Some workmen prefer to make the scratches with the *megebo* in the form of small spirals, others in the form of large spirals, but the general principle of the method employed with their mirrors appears to be always the same,—the face of the mirror is scratched with a blunted piece of iron, and becomes slightly convex, the back, therefore, becoming concave.

After the operation with the "distorting rod" the mirror is very slightly scraped with a hand-scraping tool to remove the scratches

and to cause the face to present a smooth surface for the subsequent polishing.

In the case of thick mirrors the convexity is first made by cutting with a knife, and the "distorting rod" applied afterwards. But in connection with this cutting process of thick mirrors there is one very interesting point. If the maker finds on applying from time to time the face of the mirror to a hard clay concave pattern, and turning it round under a little pressure, that a portion of the surface has not been in contact with the pattern, in other words, that he has cut away this portion too much, then he rubs this spot round and round with the *megebo* until he has restored the required degree of convexity. Here again then scratching on the surface produces convexity.

Now, why does the scraping of the "distorting rod" across the face of the mirror leave it convex? During the operation it is visibly concave. The metal must receive then a kind of "buckle," and spring back again so as to become convex when the pressure of the rod is removed. It might in such a case reasonably be expected that the thicker parts of the mirror would yield less to the pressure of the rod than the thinner, and so would be made less convex, or even they might not spring back, on the withdrawal of the rod, and so remain actually concave. Again, since we find that scraping the face of a mirror is the way in which it is made convex, and the back therefore concave, we might conclude that a deep scratch on the back would make the back convex and the face slightly concave. Such a concavity, as we have proved, would explain the phenomenon of the bright line appearing in the reflection of sunlight on the screen which was observed by Professor Atkinson to correspond with the scratch on the back.

It appears then that the magic of the Eastern mirror results from no subtle trick on the part of the maker, from no inlaying of other metals, or hardening of portions by stamping, but merely arises from the natural property possessed by thin bronze of buckling under a bending stress, so as to remain strained in the opposite direction after the stress is removed. And this stress is applied partly by the "distorting rod," and partly by the subsequent polishing, which, in an exactly similar way, tends to make the thinner parts more convex than the thicker.

Polishing.—After the scratches produced by the *megebo* are removed the mirror is first polished with a whetstone called either *iyodo*, "whetstone from the province of Iyo," or *shiroto*, "white whetstone." Afterwards a whetstone called *tenshimado*, "whetstone from the province Tsushima," or the powder *to-no-ko*, previously described, is used. Thirdly, a piece of charcoal, prepared from the *ho* tree (*Magnolia hypoleuca*) is rubbed over the surface. The face now becomes fairly smooth, but it still generally contains some few cavities; these the maker fills up from a stock of copper balls of various sizes which he

has at hand, and which are obtained from the cinders of a copper-furnace. The cavities when thus filled up are well rubbed so as to escape notice, but they may usually be detected by looking at the mirror obliquely.

It was perhaps the presence of these bits of copper in the mirror which Ou-tseu-hing saw broken up in the 13th century, that misled him into concluding that the phenomenon of the magic mirror was produced by the inlaying of denser copper in a portion of the face exactly corresponding with the design on the back.

When the face of the mirror has been made quite smooth, an amalgam consisting, according to the Tokio makers, of half tin and half mercury, with perhaps a trace of lead, or of

Tin	69·36 per cent.,
Mercury	30 ,,
Lead	0·64 ,,

according to the analysis of MM. Champion and Pellet ("Industries de l'Empire Chinois") is rubbed over the surface with a stiff straw brush or with the hand. The mirror is finally wiped clean with a soft kind of paper, *mino-gami*, "paper from the province Mino," which is considered to scratch the surface less than silk. Leather was formerly never employed in polishing, as it would have been considered impious to pollute so holy a thing as a mirror by touching it with the skin of an animal; for under the old feudal system in Japan, workers in skins, saddlers, and others, belonged to the Eta or pariah class.

When mirrors possessed by private people require brightening up, in consequence of the surface tarnishing, the paste produced when razors are sharpened on a hone is usually rubbed over the face of the mirror.

III. "On the Torsional Strain which remains in a Glass Fibre after release from Twisting Stress." By J. HOPKINSON, D.Sc., F.R.S. Received October 4, 1878.

It has long been known that if a wire of metal or fibre of glass be for a time twisted, and be then released, it will not at once return to its initial position, but will exhibit a gradually decreasing torsion in the direction of the impressed twist. The subject has undergone a good deal of investigation, especially in Germany. The best method of approximating to an expression of the facts has been given by Boltzmann ("Akad. der Wissensch. Wien," 1874). He rests his theory upon the assumption that a stress acting for a short time will

FIG. 1.

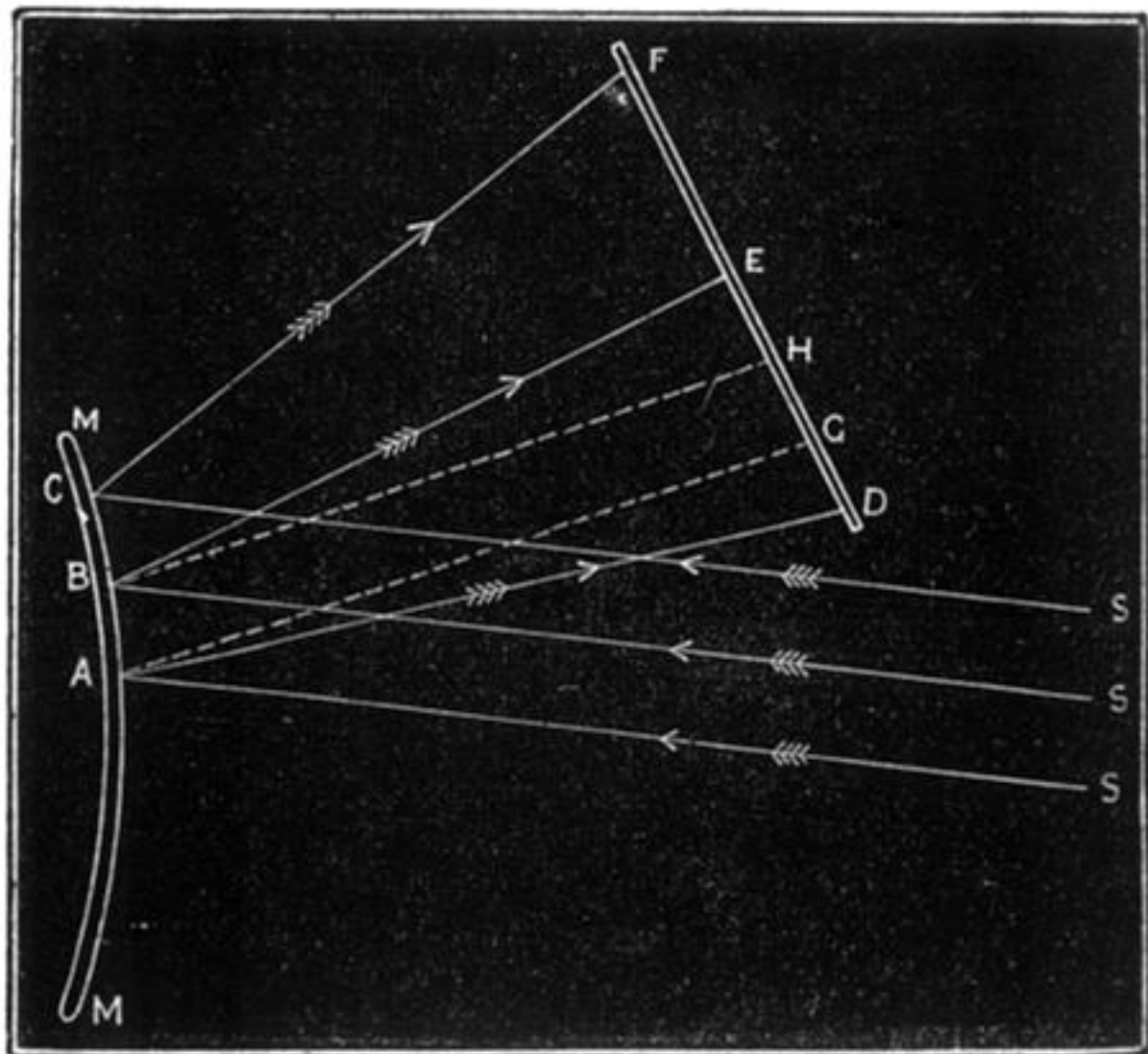


FIG. 2.

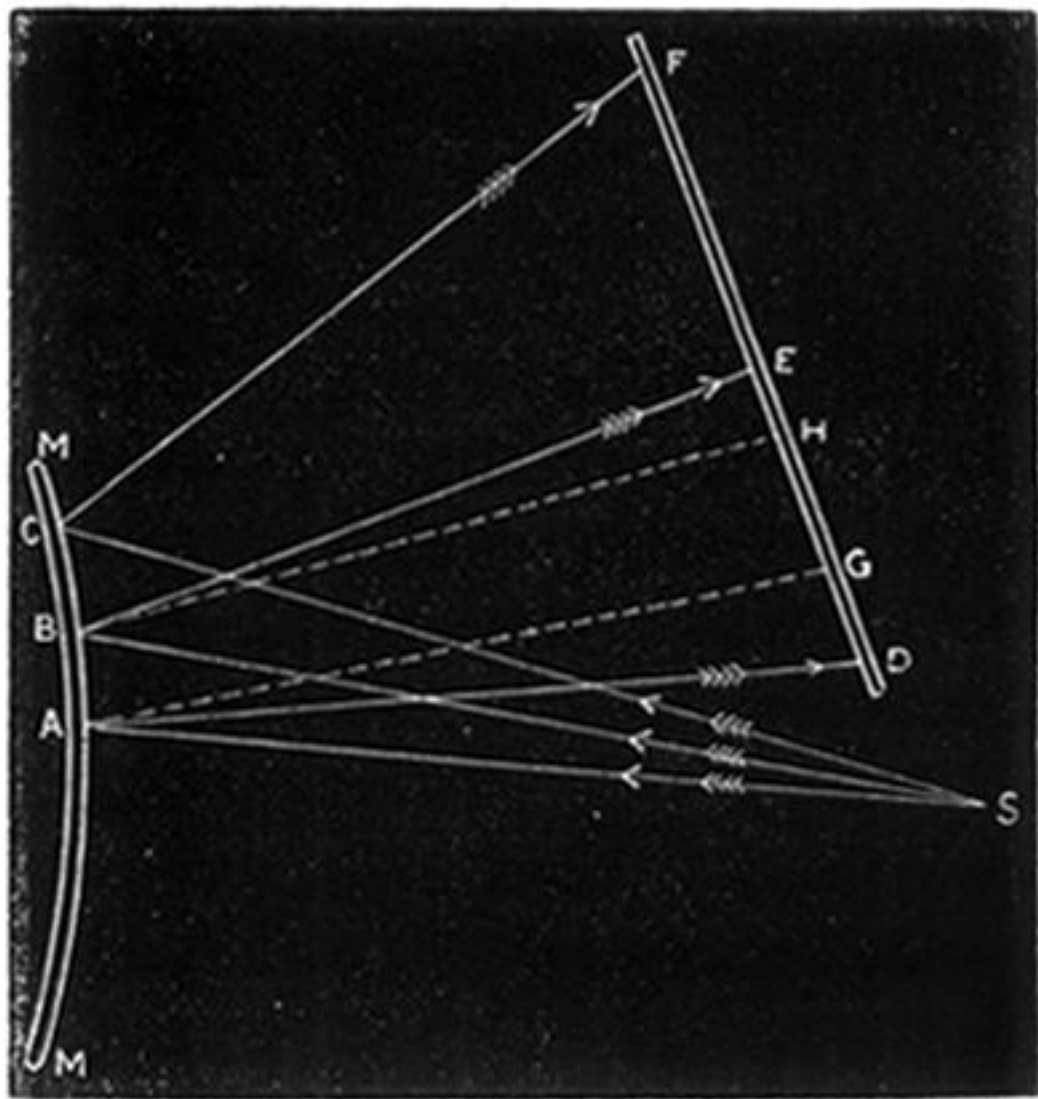


FIG. 3.

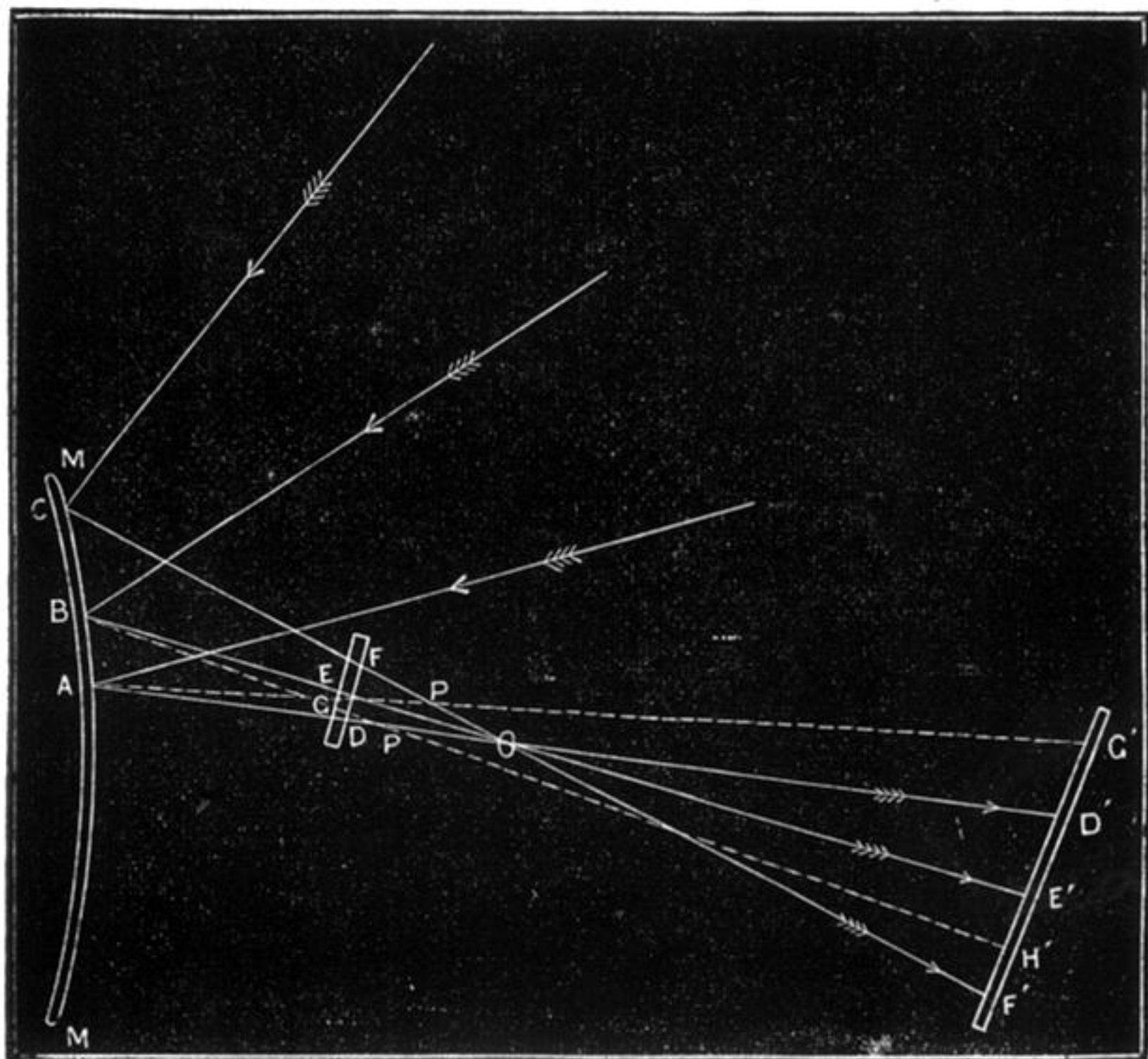


FIG. 4.

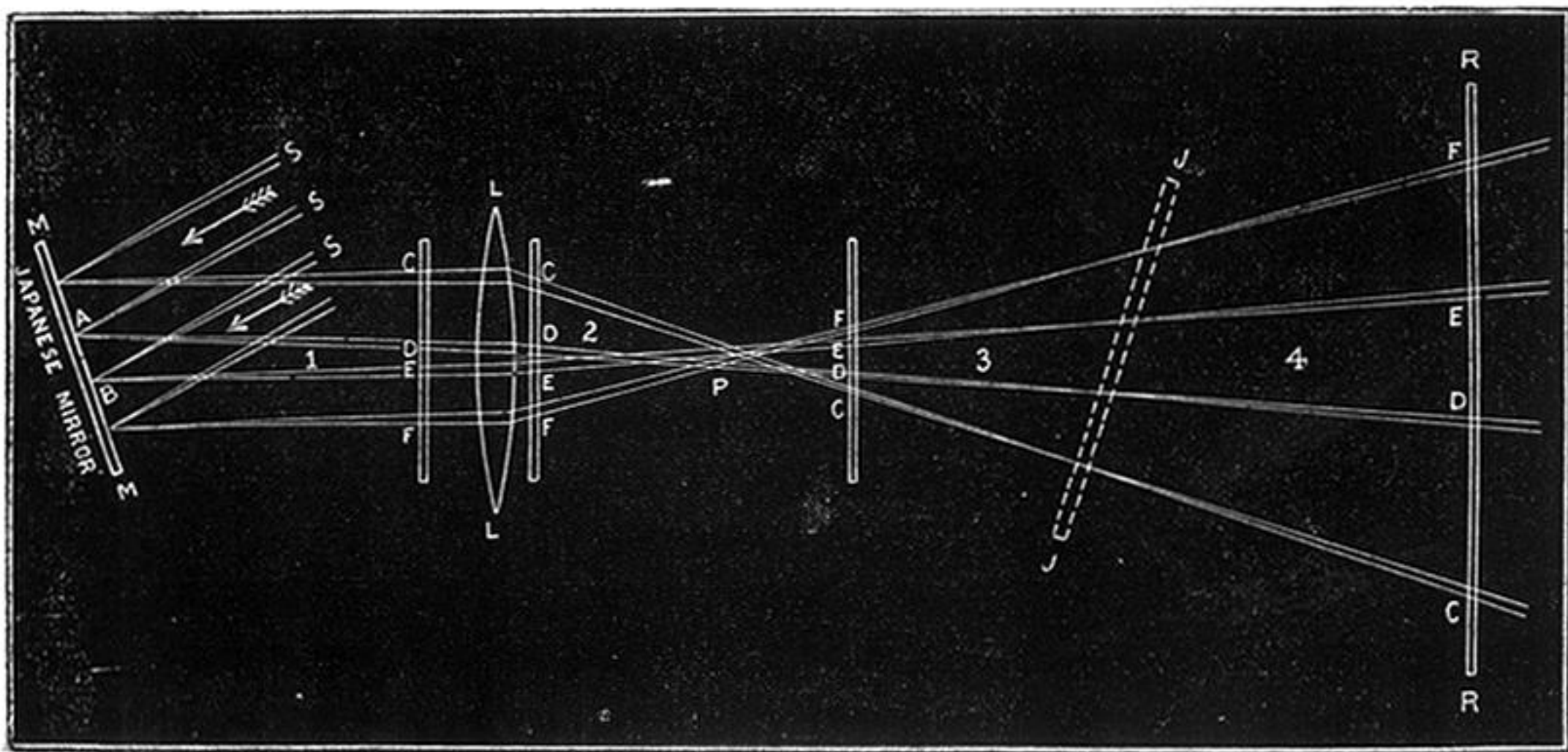


FIG. 5.

