ing as a striking example of the production of "ground-ice," the explanation of which has been a puzzle to the physicist. The explanation which you have given is that which most readily suggests itself to those familiar with the experiments of Dr. Wells, and, indeed, is that which was most generally adopted previous to the researches of Melloni. He has shown that terrestrial radiation or heat of low intensity, is interrupted by the thinnest sheet of water. It is true, that the more intense rays of heat from the sun penetrate to a considerable distance below the surface of still water, but the less intense rays do not enter the water to any depth, and it is probable that by far the greater portion of a beam of solar radiation is stopped at the surface of water. Ground-ice is formed at the bottom of streams of running water, adhering to stones, grass, or other solid bodies. The explanation given, I think by Arago, is as follows: The water at the surface is cooled down below the point of congelation, when, by the motion of the water in the stream, it is brought into contact with a solid body at the bottom, which, acting as a nucleus of crystallization, immediately determines its solidification. This explanation will apply equally to the case referred to you, in which the water from the surface is drawn down by the discharge from the pipe. I think it probable that the whole subject requires further elucidation, and it is on this account I have taken the liberty to direct your attention to the facts I have stated.

JOSEPH HENRY,

PROF. DOUGLASS, University of Michigan.

The experiments of Melloni, as well as the explanations of Arago, of the formation of "ground-ice," I was familiar with at the time I gave my views last winter, but deemed them inadequate to the explanation of the singular phenomena, for the following reasons:

First. At 89.2° of temperature water has its maximum density. This is about 7° above the freezing point. The cooling takes place at the surface, and as the temperature arrives at 89.2° the cooled water would, by virtue of its diminished specific gravity, remain at the surface. I can scarcely conceive that the current of Detroit River, or the discharge from the pipe, would be sufficient to cause the water to descend twenty-five feet against the force of gravity.

Second. Why is it the ice ceases to form on the strainer as soon as the river is covered with ice, unless it is because the ice intercepts the radiation?

Prof. Henry is probably not aware of the moderate current of the river, or the fact last mentioned.

I send you the above letter from the distinguished Professor, that the public may know the intense interest that scientific men feel in the solution of this mysterious problem. I cannot but express the hope that the Water Commissioners will take measures to test the truth of these theories the coming winter.

S. H. DOUGLASS.

On Magnetical Errors, Compensations, and Corrections, with special reference to iron ships and their compasses. By Professor AIRY.

From the London Athenæum, April, 1865.

Prof. Airy has given three lectures "On Magnetical Errors," &c., at the old lecture theatre of the South Kensington Museum. These lectures were of so much importance as to deserve the utmost publicity.

The subject was treated under the following heads: I. Terrestrial magnetism and the magnetism of permanent magnets. II. Transient induced magnetism of iron. III. Sub-permanent magnetism of iron. IV. Correction of magnetic disturbing forces. V. Magnetism of ships, especially of iron ships, and correction of their magnetic disturbing forces on the ship's compass.

From the Professor's notes we give the following synopsis:

1. *Terrestrial Magnetism and the Magnetism of Permanent Magnets.*—1. Every magnet has two opposite poles, possessing different properties.

2. Every bar-magnet, when freely suspended, takes a definite position, one end pointing to the magnetic north. (The end which points

to the north is usually called the "marked end;" in the magnets used in the illustration of the lectures, it will be distinguished as the end painted *red*, the opposite end being painted *blue*.) In the following articles the words "north" and "south" are always understood as meaning "magnetic north" and "magnetic south."

3. The force which directs a magnet is not simply a force attracting the marked end towards the north horizon, or a force attracting the unmarked end towards the south horizon; but, if it consist entirely of attraction, is composed of equal attractions of those two kinds. It may consist, wholly or in part, of repulsion of the marked end from the south and repulsion of the unmarked end from the north; but if so, those repulsions are equal. Or, the north part of the earth may attract the red end and repel the blue with equal forces; or the south part of the earth may attract the blue and repel the red, but the forces must be equal. This is proved by the fact that the magnet, as a whole, is not drawn north or south.

4. The direction of one end of a freely suspended magnet towards the north will be used as the practical definition of the marked end of a magnet.

5. The marked end of one magnet repels the marked end of another magnet, whether it be presented sideways or endways. In like manner, the unmarked end of one magnet repels the unmarked end of another. But the marked end of one attracts the unmarked end of another, and *vice versa*. When a magnet cannot be conveniently suspended, this property may be used, with the assistance of another suspended magnet or compass, for distinguishing the blue and red ends. The points in which the attractive and repulsive powers appear to be concentrated are called the "poles of the magnet." It may be understood, without great inaccuracy, that the distance of each pole from the end of the magnet is about one-twelfth of the whole length.

6. A horse-shoe magnet is merely a bent bar-magnet, with poles possessing the same properties as those of a straight bar-magnet.

7. If above a large freely suspended bar-magnet a small magnet be freely suspended, when it is raised high it takes the same position as the large magnet; when it is lowered near to it it takes the opposite position, and at a certain intermediate height it is indifferent as to position, no force (apparently) acting on it at all.

8. These observations show that the magnetic attraction of the earth is similar in character to that of a bar-magnet, but that the part of the earth which resembles in its magnetism the marked or red end of a magnet is on the south side of the place of observation.

9. General principle of ascertaining the relative magnitudes of forces by vibrations of a suitable apparatus. The relative magnitudes of the terrestrial horizontal magnetic forces at different parts of the earth may be ascertained by observing the vibrations of the same magnet at different places. The forces thus found vary very greatly, being large near the irregular line called the earth's magnetic equator, and becoming insensibly small near the places called the magnetic poles of the earth.

10. In the preceding articles it has been supposed that the magnet

is constrained, either by the nature of its mounting or by the application of weights, to preserve a horizontal position, as it ought to do, in compass-cards, (the idea of allowing their needles to dip being totally erroneous.)

11. If the magnet is perfectly free, as in the instance of a dipping-needle, it takes a position inclined to the horizon; the marked end of the magnet is greatly depressed, pointing, at Greenwich, 68° below the north horizon, or much nearer to the vertical than to the horizontal direction. The direction thus taken by the free magnet is called "the direction of dip," and the plane perpendicular to it is called "the equatorial plane." (This "equatorial plane" is carefully to be distinguished from "the earth's magnetic equator," Article 9.)

12. Anticipation of the section on induction. Magnetization of a bar, or a reversion of its poles, by "double touch."

13. It is made certain, by reversing the poles of the dipping-needle, that the dipping is not produced by want of balance of the needle, but is a real result of the inclined direction of terrestrial magnetism.

14. At Greenwich, it is inferred from the direction of the dipping-needle, that the horizontal part of terrestrial magnetic force is less than the vertical part in the proportion of 40 to 99, that it is less than the whole inclined force in the proportion of 3 to 8, and that the vertical force is less than the whole inclined force in the proportion of 51 to 55; all very nearly.

15. Exhibition of the dips in different parts of a meridian of the earth. At the magnetic poles the dip is vertical, and there is no horizontal force. At the magnetic equator there is no dip. South of the magnetic equator the unmarked end of the needle dips. The magnitude of the total inclined force is rather less near the equator than in other parts of the earth, (it may be stated roughly as one-half of that near the magnetic poles,) but it is entirely effective in the horizontal direction.

16. Disturbance of a suspended magnet by a magnet placed below it. When the lower magnet has its marked end to the north, the directive force on the upper magnet is diminished; and when the lower magnet has its marked end to the south, the directive force on the upper magnet is increased, as is shown by its times of vibration.

17. If the lower magnet is made to rotate in a horizontal plane the position of the upper magnet is disturbed. During half the rotation the marked end of the upper magnet is turned somewhat to the east, and during the other half it is equally turned towards the west. The deviation vanishes when the lower magnet lies north and south, either way. The direction of disturbance is that given by the repulsion of similar poles or the attraction of different poles. This disturbance is sometimes called "semicircular deviation."

18. It is important to ascertain how this semicircular deviation will vary in different parts of the earth, (where, as stated in Article 9, the magnitudes of the terrestrial horizontal force vary greatly,) supposing the same lower magnet to be used, and at the same distance from the upper magnet.

19. Recourse must be had to the mechanical theory of "the com-

position of forces," the most important theory in the whole circle of sciences, and with which every student of any philosophical subject ought to be perfectly acquainted. Theorem of the "parallelogram of forces."

20. If with a primary force (as the terrestrial horizontal magnetic force acting on either pole of a magnet) there be combined a new force in a different direction, (as the force of the lower magnet acting on the same pole,) the direction of the resultant force will deviate from the direction of the primary (or terrestrial) force. But the greater is the primary force the smaller is the deviation. Thus, if a ship carries a magnet under or near her compass, this magnet will produce but a small deviation when the ship is near the terrestrial magnetic equator, (where the terrestrial horizontal magnetic force is large,) but will produce a great deviation in high magnetic latitudes, (where the horizontal magnetic force is small.)

21. If the lower or second magnet be not immediately below the upper or first magnet, but be on one side, whether at the same level or not, being, however, in the position "broadside on," and if its supporting frame rotate round the vertical axis of the first magnet, the deviation which it produces is semicircular, (see Article 17,) and vanishes when the second magnet lies north and south. The same holds when the second magnet is "end on." But if the second magnet is in an intermediate or inclined position, the deviation is semicircular, but the vanishing of the deviation occurs when the second magnet lies in a position varying from north or south.

22. But, supposing the second magnet to be lower, there is one important difference of these actions. If the first magnet is free to dip, then a second magnet broadside on will not cause the first magnet to dip, but a magnet end on, or nearly end on, will cause the first magnet to dip.

22*. The proportion of the actions of one magnet on another may be calculated with great accuracy by considering each magnet to consist of two centres of force (attractive or repulsive) near its extremities, acting on the similar centres of force of the other magnet, with equal force in all directions, varying inversely as the square of the distance. It results from this that, in any given direction of the line joining their centres, the directive force of one needle upon another varies nearly as the inverse cube of their distance.

23. The "astatic needle" is made by fixing two magnets of equal power on different parts of the same frame, with marked ends in opposite positions. The united frame is then insensible to terrestrial magnetism, but either magnet separately will be affected by the local action of a magnet near it.

23*. The astatic needle may be used to exhibit strikingly the effects of one magnet on another. Thus, if the external magnet be below or at the side of the lower needle of the astatic pair, the latter takes an opposite position as regards red and blue ends; but if the external magnet be moved, without change of direction, so as to present an end to the lower needle of the astatic pair, the latter immediately turns so as to take a similar position as regards red and blue ends.

II. *Transient Induced Magnetism of Iron.*—24. If a soft iron bar, which has not been subject to any special violence, be presented endways to the centre of a freely suspended magnet, the direction of the iron bar being either east or west in the horizontal plane, or any direction included in the equatorial plane, (see Article 11,) then no deviation whatever is produced in the magnet. If it be presented endways to either pole of the magnet, it slightly attracts that pole, (a fact to be explained below, Article 26.) It is indifferent which end of the iron bar be presented.

25. If a second magnet, with an iron bar in front, but separated by a small interval, be presented to the first magnet, and deviation be thus caused, then, upon causing the iron bar to touch the second magnet, the deviation of the first magnet is immediately increased, decreasing again when the iron is separated from the magnet. This shows that the contact of the second magnet has converted the soft iron, for the time of contact only, into a magnet whose poles are in the same relative position as those of the second magnet; and therefore a red pole of the second magnet produces a blue pole in that part of the iron which is next it, or *vice versa*. This production of magnetic power in iron by the action of an external magnet is called "induction."

26. This explains the attraction of soft iron by either pole of a magnet. For the magnet-pole, by induction, produces a pole of the opposite character in the nearest part of the iron; and between poles of opposite character there is attraction, (Article 5.)

27. If a bar of soft iron be held in a vertical position, then, upon raising and depressing it, it is found that the end which is lower repels the red end of the magnet and attracts the blue end, and the end which is higher attracts the red end of the magnet and repels the blue end. The bar has become a genuine magnet with red end downwards. But this magnetism is only transient; for upon inverting the iron bar the properties of its ends are inverted, and if it is placed in the equatorial plane (Article 11) they vanish entirely.

28. This is explained by induction produced by the powerful terrestrial magnetic force in the vertical direction, (Article 14.)

29. The amount of action depends, in some degree, upon the connexion of the parts of the mass of iron. The same mass in the same general form, but divided into several parts, produces a smaller effect.

30. If a mass, as a cannon-ball, be made to rotate round the suspended magnet in the same horizontal plane, it produces no disturbance when it is north, or south, or east, or west of the magnet's centre; but in the intermediate quadrants it produces deviation, changing its character in every successive quadrant, which may be represented (in memory) by saying that "the mass attracts that pole of the magnet which is nearest to it." This is called "quadrantal deviation."

31. The explanation is, that the induction produced by the horizontal part of terrestrial magnetic force converts the mass of iron into a horizontal magnet with red pole always towards the north. (A small magnet carried round always in that position produces a similar effect.) It is to be remarked, that the induction produced by the vertical part

of terrestrial force does not appear here, for a small vertical magnet carried round in the same manner produces no effect.

32. It may here be noticed that the quadrantal deviation thus produced in the compass by a mass of iron in the same horizontal plane is the same in all parts of the earth. For, referring to the parallelogram of forces, (Article 19,) if the "primary force" (which is here the terrestrial horizontal force) and the "new force" (which is here the force of the magnetism induced in the mass of iron) be always in the same proportion, the deviation for any definite inclination of the two forces is unaltered. Here they always are in the same proportion; because the magnetism in the iron, which is induced by the earth's horizontal force, is proportioned to it.

33. If the cannon-ball is higher or lower than the magnet, the deviation vanishes when it is north or south, but not when it is east or west, exhibiting a mixture of semicircular deviation (Article 17) with quadrantal deviation, (Article 30.) The former is produced by induction from the vertical part of the terrestrial force; it is exactly similar to the effect of a small vertical magnet (with red pole downwards, and with centre higher or lower than the deviated magnet) carried round the deviated magnet. The latter has been explained above, (Article 31.)

34. On further examination, it is seen that all effects are explained by induction in the cannon-ball, produced by the total terrestrial action in the direction of dip, converting the cannon-ball for the time into a magnet whose red end points down in the direction of dip.

34*. The law of disturbance may thus be represented (from memory). Through the centre of the magnet conceive an equatorial plane (Article 11) to pass. The mass of iron attracts that end of the magnet which is on the same side of the equatorial plane as itself.

35. Since the induced horizontal magnet (Article 31) has its red end in a position opposite to that of the earth, (Article 8,) it follows that one effect of the proximity of such a mass of iron at a lower level than the deviated magnet is, on the whole, to somewhat diminish the directive power of terrestrial magnetism.

36. The ordinary process of magnetizing a steel bar by double touch of two permanent steel magnets is a process of induction, differing from those of soft iron only in this respect, that the steel bar, when it has received the magnetism, retains it permanently.

III. *Sub-permanent Magnetism of Iron.*—37. When a bar or plate of soft iron, in a state of tremor from mechanical violence, is exposed to external magnetic action, it receives induced magnetism in the same manner as iron in a quiet state, (Articles 27 and 34;) but the induced magnetism is much more powerful, and is for a long time sensibly permanent. It does not change its direction on changing the position of the bar, (as in Article 27,) and it does not vanish in any position of the bar. The iron bar has become a true magnet, exactly similar in its action to a magnetized steel magnet. Its magnetism, however, diminishes sensibly in a few days or a few weeks, but a portion remains for many months or years. This has been called "sub-permanent magnetism."

38. The sub-permanent magnetism is most easily produced by striking an iron bar or plate under the action of terrestrial magnetism. The "magnetic anvil," consisting of two planes, one containing the direction of local dip, the other being the equatorial plane, (Article 11.)

39. If a bar or plate be placed on the dip-slope of the magnetic anvil, with its white end downwards, and be struck with a hammer, it becomes a powerful magnet, the white end having the properties of a magnet's red end, and the black end having the properties of a magnet's blue end.

40. If, now, it be reversed on the dip-slope with black end downwards, and be struck in the same manner, the black end has the properties of a magnet's red end, and the white end has the properties of a magnet's blue end, the power of the magnet being sensibly equal to what it was before.

41. If the bar, thus charged with sub-permanent magnetism, be placed on the equatorial slope of the magnetic anvil, and be struck in the same manner, all magnetism will sensibly disappear.

IV. *Correction of Magnetic Disturbing Forces.*—42. It is impossible to intercept the action of magnetic disturbing forces upon a magnet or compass by surrounding the compass, &c., with any substance whatever. Nothing is known which interrupts magnetic action, and if such a substance could be found, it would also interrupt terrestrial magnetic action, (which is of the same nature as the action of a magnet, see Article 8,) and the compass, &c., would be useless.

43. The only way of destroying the effect of one magnetic disturbing force is, to introduce another magnetic disturbing agent, whose force follows the same laws and has the same magnitude, but always acts in the opposite direction.

44. The disturbing effect of one magnet, or of several magnets, supposed to rotate round the compass, &c., in a horizontal plane, may be corrected by one magnet, or sometimes, more conveniently, by two magnets.

45. The disturbing effect of a mass of iron at the same level as the compass, which is quadrantal, (Article 30,) cannot be corrected by an equal mass on the opposite side; such an application would double the disturbance.

46. But it may be corrected by an equal mass at the position 90° distant, or by two smaller masses 90° distant each way, (and therefore opposite each other.)

47. It may also be corrected by placing another compass near to the disturbed compass.

48. The disturbance produced by an elevated or depressed mass of iron can be corrected by applying an equally elevated or depressed mass on the opposite side, which corrects the semicircular deviation, (Article 33,) but doubles the quadrantal deviation, (Articles 30 and 45,) together with a large mass 90° distant, or two masses 90° distant on each side, (either of which arrangements may be made to correct that doubled quadrantal deviation, see Article 46.)

49. Or it may be corrected by using a small magnet to correct the

semicircular part, (the small magnet being adjusted by trial to make the disturbance disappear when the mass is east or west,) and then applying a small mass or two masses 90° distant to correct the quadrantal part.

50. There is inconvenience in effecting, by a magnet, the whole or a part of the correction of a disturbance produced by terrestrial induction in masses of iron, (as is proposed in Articles 47 and 49,) because the action of the magnet is the same in all parts of the earth; whereas the disturbing force produced by induced magnetism in iron is proportional to the terrestrial force, which varies in different parts of the earth, (Article 9,) and whose direction relative to the horizon is in some places nearly inverted, (Article 15,) and thus the correction cannot be made universally effective.

51. The correction of the disturbing force of induced magnetism in one mass by the force of induced magnetism in another mass, (as is proposed in Articles 46 and 48,) is theoretically perfect in all parts of the earth, because both the disturbing force and the correcting force are proportional to the terrestrial force, and therefore they neutralize each other whatever be the magnitude and direction of that terrestrial force. This applies accurately to action on points near the centre of a compass, or applies very nearly to action on all points when the compass is small.

52. When the compass is large and has only one needle, the correction produced by a small mass of iron is not perfect, because it must be brought so close to one pole of the needle that the action on that pole is unduly large. But this inconvenience is almost entirely removed by use of the Admiralty compass with four parallel needles.

53. When the only correction to be effected is that of a quadrantal deviation, (Articles 30 and 45,) it may be abandoned entirely, provided that a compass-card with modified graduations be used; because the quadrantal deviation is the same in all parts of the earth, (Article 32,) and therefore the same modification of the compass-card which correctly alters the apparent card-reading in one part of the earth will correctly alter it in every other part.

(To be continued.)

Explosion of Steam Boilers.

From the *London Mechanics' Magazine*, April, 1866.

No. 7 explosion, by which one man was killed and five others injured, is an illustration of the unsatisfactory and dangerous character of plain cylindrical externally-fired boilers. This subject has frequently been called attention to in previous reports, but it is felt to be a duty to continue to do so as frequently as fatal explosions recur from the continued use of this class of boiler. The explosion in question took place at about quarter past ten o'clock on the morning of Monday, January 29, at a colliery which was not under the inspection of the Association. The boiler was about 30 ft. long, 3 ft. in diameter, and made of plates laid longitudinally, and $\frac{3}{8}$ in. in thickness,