Class 35
No 10

J H.

Scientific investigations at Princeton.

Letter to Rev S. B. Dod.

Dec 1st 1876.

My dear Sir.

In compliance with your request that I would give an account of my scientific researches ~~in science~~ during my connection with the College of New Jersey I furnish the following brief statement of my labors within the period mentioned.

I. Previous to my call from the Albany Academy to a professorship in the College of New Jersey I had made a series of researches on electro-magnetism in which I developed the principles of the electro-magnet and the means of accumulating the magnetic power to a great extent and had also applied this power in the invention of the first electro magnetic machine that is, a mechanical contrivance by which electro magnetism was applied as a motive power. I soon saw, however, that the ~~power~~ application of this power was but an indirect method of employing the energy derived from the combustion of coal ~~in the steam engine~~ and therefore could never compete on the score of expense with that agent as a means

of the propelling of machinery, but that it might be used in some cases in which expense of power was not a consideration to be weighed against the value of certain objects to be attained. A great amount of labor has since been devoted to this invention, especially at the expense of the government of the United States by the late Dr. Page, but it still remains in nearly the same condition as it was left in by myself in 1838.

I also applied while in Albany the results of my experiments to the invention of the first electro magnetic telegraph, in which signals were transmitted by exciting an electro magnet at a distance, by which means, dots might be made on paper bells were struck in succession, indicating letters of the Alphabet

In the midst of these investigations I was called to Princeton through the nomination of Dr. Jacob Green then of Philadelphia, and Dr. John Torrey of New York. I arrived in Princeton in November 1832 and as soon as I became fully settled in the chair which I occupied, I recommenced my investigation

constructed a still more powerful electro magnet than I had made before, one which would sustain over 3000 lbs. and with it illustrated to my class the manner in which a large amount of power might by means of a relay magnet be called into operation at the distance of many miles. I also made several modifications in the electro magnetic machine before mentioned and just previous to my leaving for England in 1837, again turned my attention to the telegraph

I think the first actual line of telegraph using the earth as a conductor was made in the beginning of 1838. A wire was extended across the front campus of the College grounds from the upper story of the Wray building ~~one end terminating in a well near my residence and the other in a well at the opposite side~~ to the Philosophical Hall on the opposite side, each end terminating in the wells. Through this wire signals ~~messages~~ were sent from time to time ~~during the day~~ from my house to my laboratory.

The electro magnetic telegraph was first invented by me in Albany in 1830. Prof. Morse according to his statements conceived the idea of an electro-magnetic telegraph in his voyage across the ocean in 1832. but did not until several years after-

wards (1837) attempt to carry his ideas into practice, and when he did so he found himself so little acquainted with the subject of electricity that he could not make ~~the~~ his simple machine operate through the distance of a few yards. In this dilemma he called in the aid of Dr Gale who was well acquainted with what I had done in Albany and Princeton having visited me at the latter place. He informed Prof. Morse that he had not the right kind of a battery nor the right kind of magnets, whereupon the Professor turned the matter over to him ~~entirely~~ and with the knowledge he had obtained from my researches he was enabled to make the instrument work through a distance of several miles. For this service Prof Morse gave him a share of his patent, which he afterwards purchased from him for $15 000.

At the time of making my original experiments on electro-magnetism in Albany I was urged by a friend to take out a patent both for its application to machinery and

to the telegraph but this I declined on the ground that I did not then consider it compatible with the dignity of science to confine the benefits which might be derived from it to the exclusive use of any individual. In this perhaps I was too fastidious. I first became accidentally acquainted with Mr. Morse in 1838. while he was applying for assistance to carry out his idea of a telegraph. He explained his plan of operations and I was surprised to find it so nearly the same in general arrangement as my own. Not knowing at the time that he had derived any assistance from my invention through Dr. Gale or otherwise I resolved not to interfere with his endeavor to obtain means to carry out the idea but gave him a certificate that science was ripe for the application of the telegraph and that it would be a success were the means afforded for its application to practical use. He afterwards visited me several times at Princeton and I freely gave him any information he might require applicable to the telegraph. Our relations

were of the most harmonious character until a work was published under Prof Morse's sanction giving a history of the telegraph in which I thought great injustice was done to myself. I was then called upon to examine the invention of the House printing electro-magnetic telegraph and after careful study I gave a certificate to the effect that this was a very ingenious invention that it would work and did not in any way interfere with the claims of Prof. Morse. A company was accordingly soon formed and this telegraph put in operation. Law suits afterwards occured on account of infringements in which I was reluctantly obliged to give my testimony and which afterwards called forth from Prof. Morse a pamphlet the object of which was to show that I was guilty of perjury. In briefly stating my claims to the invention of the electro-magnetic telegraph I may say I was the first to bring the electro-magnet into the condition necessary to its use in telegraphy and also to

point out its application to the telegraph
and to illustrate this
by constructing a working ~~model~~ telegraph and had
taken out a patent for my labors at that time
Mr. Morse could have had no ground on which
to found his claim for
a patent for his invention.
To Mr. Morse however great credit is due for his alphabet and for his
perseverance in bringing the telegraph into practical use
My next investigation after being settled
at Princeton was in relation to electro dynamic
induction. Mr. Faraday had discovered that when
a current of galvanic electricity was passed through
a wire from a battery a current in an opposite
direction was induced in a wire arranged paral-
lel to this conductor. I discovered that an in-
duction of a similar kind took place in the primary
conducting wire itself, so that a current which in its
passage through a short wire conductor would neither
produce sparks nor shocks, would, if the wire were
sufficiently long, produce both those phenomena. The
effect was most strikingly exhibited when the conduc
tor was a flat ribbon covered with silk rolled into the
form of a helix. With this, brilliant deflagrations and
other electrical effects of high intensity were produced
by means of a current from a battery of low intensity

such as that of a single element.

(III) A series of investigations was afterwards made which resulted in producing inductive currents of different orders, having different directions, made up ~~as it were~~ of waves alternately in opposite directions. It was also discovered that a plate of metal of any kind introduced between two conductors neutralized this induction and this effect was afterwards found to result from a current in the plate itself. It was afterwards shown that a current of quantity was capable of producing a current of intensity, and vice versa, a current of intensity would produce one of quantity

(IV) Another series of investigations of a parallel character was made in regard to ordinary or frictional ~~&~~ electricity. In the course of these it was shown that electro-dynamic inductive action of ordinary electricity was of a peculiar character and that effects could be produced by it at a remarkable distance. For example, if a shock were sent through a wire on the outside of a building, electrical effects could be exhibited in a parallel wire

within the building. As another illustration of this it may be mentioned that when a discharge of a battery of several Leyden jars was sent through the wire before mentioned, stretched across the campus in front of Nassau Hall, an inductive effect was produced in a parallel wire, the ends of which terminated in the plates of metal in the ground in the back campus at a distance of several hundred ~~yards~~ feet from the primary current, the building of Nassau Hall intervening. The effect produced consisted in the magnetisation of steel needles. In this series of investigations the fact was discovered that the induced current as indicated by the needles appeared to change its direction with the distance of the two wires, and other conditions of the experiment, the cause of which for a long time baffled inquiry but was finally satisfactorily explained by the discovery that the discharge of electricity from a Leyden jar is of an oscillatory character, a principal discharge taking place in one direction and im-

mediately afterwards a rebound in the opposite and so on forward and backward until the equilibrium is obtained.

V The next series of investigations related to atmospheric induction. The first of these consisted of experiments with two large kites, the lower end of the string of one being attached to the upper surface of a second kite, the string of each consisting of ~~both furnished with~~ a fine wire ~~as a string~~ the terminal end of the wire being coiled around an insulated drum. I was assisted in these experiments by Mr. Brown of Philadelphia who furnished the kites. When they were elevated ~~in~~ a time ~~day~~ when the sky was perfectly clear, ~~of clouds~~ sparks were drawn of surprising intensity and pungency, the electricity being supplied ~~by that of~~ from the air and the intensity being attributed to the induction of the long wire on itself.

VI The next series of experiments pertaining to the same class was on the induction from thunder clouds. For this purpose the ~~the~~ covering of the roof of ~~the house~~ ~~which~~ the house in which I resided ~~my residence~~

~~was of tin~~ was used as an inductive plate. A wire was soldered to the edge of the roof near the gutter, was passed into my study and out again through holes in the window sash and terminated in connection with a plate of metal in a deep well immediately in front of the house. By breaking the continuity of that part of the wire which was in the study, and introducing into the opening a magnetising spiral, ~~needles~~ placed in this needles could be magnetised by a flash of lightning so distant that the thunder could scarcely be heard. The electrical disturbance produced in this case was also found to be of an oscillatory character, a discharge first passing through the wire from the roof to the well, then another in the opposite direction, and so on until the equilibrium was restored. This result was arrived at in this case as well as in that of the Leyden jar before mentioned by placing the same needle or a similar needle in succession in spirals of greater and greater numbers of turns; for example, in a spiral of a single turn, the needle would be magnetised plus

or in the direction due to the first and more powerful wave. By increasing the number of coils the action of the second wave became dominant so that it would more than neutralize the magnetism produced by the first wave and leave the needle minus. By farther increasing the number of turns the third wave would be so exalted as to neutralize the effects of the preceding two, and so on. In the case of induction by lightning the same result was obtained by placing a number of magnetising spirals of different magnetising intensities in the opening of the primary conductor, the results of which was to produce the magnetisation of an equal number of needles plus and minus indicating alternate currents in opposite directions.

~~VII~~. In connection with this class of investigations a series of experiments was made in regard to lightning rods. It was found ~~in their investigation~~ that when a quantity of electricity was thrown upon a rod the lower end of which was connected with a plate of metal sunk in the water of a deep well, that the

electricity did not descend silently into the water, but that sparks could be drawn from every part of the rod sufficiently intense to explode an electrical pistol and to set fire to delicate inflammable substances. The spark thus given off was found to be of a peculiar character, for while it produced combustion, it gave a slight shock and fired the electrical pistol it scarcely, at all, affected the gold leaf electroscope. Indeed it consisted of two sparks, one from the conductor and the other to it, in such quick succession that the rupture of the air by the first, served for the path of the second. The conclusion arrived at was that during the passage of the electricity down the rod, each point in succession received a charge analogous to the statical charge of a prime conductor, and that this charge in its passage down the rod was immediately preceded by a negative charge the two in their passage past the point at which the spark was drawn giving rise to its duplex character.

It was also shown by a series of experiments in transmitting a powerful discharge through a portion of air, that the latter, along the path of discharge, was endowed for a moment with an intense repulsive energy. So great is this that in one instance when an electrical discharge from the clouds passed between two chimnies through the cockloft of a house the whole roof was lifted from the walls. It is to this repulsive energy or tendency in air to expand at right angles to the path of a stroke of lightning that the mechanical effects which accompany the latter are generally to be attributed

In connection with this series of investigations an experiment was devised for exhibiting the screening effect within a space enclosed with a metallic envelope of an exterior discharge of electricity. It consisted in coating the outside of a hollow glass globe with tinfoil and afterwards inserting through a small hole in the side a delicate gold leaf electrometer. The latter being observed through a small opening in the tinfoil was found to be unaffected by a discharge of electricity passed over the outside coating.

VIII

Another series of investigations was on the phosphorogenic emanation from the sun. It had long been known that when the diamond is exposed to the direct rays of the sun, and then removed to a dark place, it emits a pale blue light which has received the name of phosphorescence. This effect is not peculiar to the diamond but is possessed by a number of substances, of which the sulphuret of lime is the most prominent. It is also well known that phosphorescence is produced by exposing the substance to the electric discharge. Another fact was discovered by Becquerel of the French Institute that the agent exciting phosphorescence traverses with difficulty a plate of glass or mica while it is transmitted apparently without impediment through plates of ~~rock~~ black ~~crystal~~ mart impervious to light.

My experiments consisted in the first place in the reproduction of these results and afterwards in the extension of the list of sub-

stances which possess the capability of exhibiting phosphorescence, as well as the effects of different interposed media.

It was found that among a large number of transparent solids some were permeable to the phosphorescing agent and others impermeable, or imperfectly permeable. Among the former were ice, quartz, common salt, alum. Among the latter glass, mica, tourmaline, camphor &c. Among liquid permeable substances were water, solutions of alum, ammonia while among the impermeable liquids were most of the acids, sulphate of zinc, sulphate of lead, alcohol &c.

It was found that the emanation took place from every point of the line of the electric discharge, but with more intensity from the two extremities, and also that the emanation producing phosphorescence whatever be its nature, when reflected from a mirror obeys the laws of the reflection of light, but no reflection was obtained from a surface of polished glass. It is likewise refracted by a

prism of rock salt in accordance with the laws of the refraction of light. By transmitting the rays from an electrical spark through a series of very thin plates of mica it was shown that the emanation was capable of polarization & consequently of double refraction.

(IX.) The next series of investigations was on a method of determining the velocity of projectiles. The plan proposed for this purpose consisted in the application of the instantaneous transmission of the electrical action to determine the time of the passage of the ball between two screens placed at a short distance from each other in the path of the projectile. For this purpose, the observer is provided with a revolving cylinder moving by clockwork at a uniform rate, and of which the convex surface is divided into equal parts indicating a fractional part of a second. The passage of the ball through the screen breaks a galvanic circuit the time of which is indicated on the revolving cylinder by the terminal spark produced in a wire surrounding a bundle of iron wires. Since the publi-

cation of this ~~apparatus~~ invention various other plans ~~founded~~ ~~resting~~ on the same principle have been introduced into practice.

~~The~~ A seventh series of experiments was in regard to the relative heat of different parts of the sun's disc and especially to that of the spots on the surface. These were made in connection with Prof. S. Alexander and consisted in throwing an image of the sun on a screen in a dark room by drawing out the eye piece of a telescope. Through a hole in the screen the end of a sensitive thermopile was projected the wires of which were connected with a galvanometer. By slightly moving the smaller end of the telescope different parts of the image of the sun could be thrown on to the end of the thermopile and by the deviation of the needle of the galvanometer the variation of the heat was indicated. In this way it was proved that the spots radiated less heat than the adjacent parts and that all parts of the sun's surface did not give off an equal amount of heat.

XI.2

~~Another~~ Another series of experiments was made with what was called a thermal telescope. This instrument consisted of a long hollow cone of pasteboard lined ~~internally~~ with silver leaf and painted ~~without with a coating of~~ outside with lamps black. The angle at the apex of this cone was such as to cause all the parallel rays from a distant object entering the larger end of the cone to be reflected on to the end of a thermopile the poles of which were connected with a delicate galvanometer. When the axis of this conical reflector was directed towards a distant object of greater or less temperature than the surrounding bodies, the difference was immediately indicated by the deviation of the ~~galvanic~~ needle of the galvanometer. For example, when the object was a horse in a distant field the radiant heat from the animal was distinctly perceptible at a distance of at least ~~one eighth of~~ several hundred yards. ~~a mile~~. When this instrument was turned towards the celestial vault the radiant heat was observed to increase from the zenith

downwards, when directed however to different clouds it was found to indicate in some cases a greater and in others a less degree of radiation than the surrounding space.

When the same instrument was directed to the moon a slight increase of temperature was observed over that of the adjacent sky but this increase of heat was attributed to the reflection of the heat of the sun from the surface of the moon and not to the heat of the moon itself. To show that this hypothesis is not inconsistent with the theory that the moon has cooled down to the temperature of celestial space, a concave mirror was made of ice and a thermo-pile placed in the more distant focus, when a flame of hydrogen rendered luminous by a spiral of platinum wire was placed in the other focus, the needle of the galvanometer attached to the pile indicated a reflection of heat; care being taken to shade the pile by a ~~small~~ screen with a small opening introduced between it and the flame.

XII Another series of experiments connected with the preceding may be mentioned here. It is well known that the light from a flame of hydrogen is of very feeble intensity, the same is the

case with that of the compound blowpipe while the temperature of the latter is exceedingly high sufficiently so to melt fine platinum wire. It is also well known that by introducing lime or other solid substances into this flame its radiant light is very much increased. I found that the radiant heat was increased in a similar ratio or in other words that in such cases the radiant heat was commensurate with the radiant light and that the flame of the compound blowpipe though of exceedingly high temperature is a comparatively cool substance in regard to radiant heat. To study the relation of the temperature of a flame to the amount of heat given off, four ounces of water were placed in a platinum crucible and supported on a ring stand over a flame of hydrogen; the ~~number of~~ minutes and seconds of time ~~were~~ then accurately noted which ~~were~~ required for the raising of the water from the temperature of 60° to the boiling point. The same experiment was repeated with an equal quantity of water with the same flame into which a piece of mica was inserted by a handle made of

a narrow slip of the same substance. With this arrangement the light of the flame was much increased, while the time of bringing the water to the boiling point was also commensurately increased thus conclusively showing that the increase of light was at the expense of the diminution of the temperature. These experiments were instituted in order to examine the nature of the fact mentioned by Count Rumford that balls of clay introduced into a fire under some conditions increases the heat given off into an apartment. From the results just mentioned it follows that the increase in the radiant heat which would facilitate the roasting of an article before the fire would be at the expense of the boiling of a liquid in a vessel suspended directly over the point of combustion.

XIII Another investigation had its origin in the accidental observation of the following fact. A quantity of mercury had been left undisturbed in a shallow saucer with one end of a piece of lead wire about the diameter of

a goose quill and six inches long plunged into it, the other end resting on the shelf. In this condition it was found after a few days that the mercury had passed through the solid lead as if it were a syphon and was lying on the shelf still in a liquid condition. The saucer contained a series of minute crystals of an amalgam of lead and mercury. A similar result was produced when a piece of the same lead wire was coated with varnish, the mercury being transmitted without disturbing the outer surface

When a length of wire of five feet was supported vertically with its lower end immersed in a vessel of mercury the liquid metal was found to ascend in the course of a few days to a height of three feet. These results led me to think that the same property might be possessed by other metals in relation to each other. The first attempt to verify this conjecture was made by placing a small globule of gold on a plate of sheet iron and submitting it to the heat of an assaying furnace, but the experiment was unsuccessful,

for although the gold was heated much beyond its melting point, it showed no signs of sinking into the pores of the iron. The idea afterward suggested itself that a different result would have been obtained had the two metals been made to adhere to each other so that no oxide could form between the two surfaces. To verify this, a piece of copper thickly plated with silver was heated to near the melting point of the metal, when the silver disappeared and after the surface was cleaned with diluted sulphuric acid it presented a uniform surface of copper. This plate was next immersed for a few minutes in a solution of muriate of zinc by which the surface of copper was removed and the surface of silver again exposed. The fact had long been observed by workmen in silver plating, that in soldering, the parts of plated metal if care be not taken ~~not~~ to heat them unduly, the silver will disappear. This effect ~~has been~~ was supposed to be produced by evaporation or the burning off as it was called of the plating. It is not im-

probable that a slow diffusion of one metal into the other takes place in the case of an alloy. Silver coins slightly alloyed with copper after having lain long in the earth are found covered with a coat of copper. This may be explained by supposing that the alloy of copper at the surface of the coin enters into combination with the carbonic acid of the soil and being thus removed, its place is supplied by a diffusion from within, and in this way it is not improbable that a large portion of the alloy may be removed in progress of time and the purity of the coin be considerably increased. It is known to the jeweller that articles of copper plated with gold lose their brilliancy after a while and that this can be restored by boiling them in Ammonia. This effect is probably produced by the ammonia acting on the copper and dissolving off its surface so as to expose the gold which by diffusion had penetrated into the body of the metal.

The slow diffusion of one metal into another at ordinary temperatures would naturally re-

quire a long time to produce a perceptible effect since it is probably only produced by ~~the change in the dimensions of~~ the minute vibrations of the parts due to variations of temperature. The same principle is applied to the explanation of the phenomenon called segregation, such as the formation of nodules of flint in masses of carbonate of lime, or in other words to the explanation of the manner in which the molecular action which is insensible at perceptible distances may produce results which would appear at first sight to be the effect of attraction acting at a distance.

XIV Another series of experiments had reference to the constitution of matter in regard to its state of liquidity and solidity, and they had their origin in the examination of the condition of the metal of the large gun constructed under the direction of Capt. Stockton by the explosion of which several prominent members of the ~~Cabinet~~ U.S. Govt at Washington were killed. It was observed in testing the bars of iron made from this gun that they varied much in ~~density~~ tensile strength in different parts, and that in breaking these bars the solution of continuity took

place first in the interior. This phenomenon was attributed to the more ready mobility of the outer molecules of the bars, the inner ones being surrounded by matter incapable of slipping and hence the rupture. A similar effect is produced in a piece of thick copper wire, each end when broken at the point of rupture exhibiting a cup-shaped surface, showing that the exterior of the metal sustained its connection longer than the interior. From these observations the conclusion was drawn that rigidity differs from liquidity more in a polarity which prevents slipping of the molecules than in a difference in the attractive force with which the molecules are held together, or that it is more in accordance with the phenomena of cohesion, to suppose that in the case of a liquid, instead of the attraction of the molecules being neutralized by heat the effect of this agent is merely to neutralize the polarity of the molecules so as to give them perfect freedom of motion around any imaginable axis.

In illustration of this subject the comparative tenacity of pure water and water in which soap had been dissolved was measured by the usual method of ascertaining the weight required to detach from the surface of each the same plate of wood suspended from the beam of a balance under the same condition of temperature and pressure. It was found by this experiment, that the tenacity of pure water was greater than that of soap and water. This novel result is in accordance with the supposition that the mingling of the soap and the water interferes with the perfect mobility of the molecules while at the same time it diminishes the attraction.

*** A series of experiments was also made on the tenacity of soap in films. For this purpose sheets of soap water films were stretched upon rings, and the attempt made to obtain the tenacity of these by placing on them fillets of cotton until they were ruptured. The thickness of these films was roughly estimated by Newton's Scale of

the colors of thin plates and from the results the conclusion was arrived at that the attractive force of the molecules of water for those of water is approximately equal to those of ice for those of ice, and that the difference in this case of the solidity and liquidity was due to the want of mobility in the ~~former~~ latter which prevented the slipping of the molecules on each other. It is this extreme mobility of the molecules of water that prevents the formation of permanent bubbles of it and not a want of attraction.

The roundness of drops of water is not due to the attraction of the whole mass, but merely to the action of the surface which in all cases of curvature is endowed with an intense contractile power.

This class of investigations also included the study of soap-bubbles and the establishment of the fact of the contractile power of these films. The curvature of the surface of a bubble tends to urge each particle toward the centre