

# DR. SCHLICK'S GYROSCOPIC APPARATUS FOR PREVENTING SHIPS FROM ROLLING.\*

BY M. WURL.

A VESSEL in a seaway is subject to periodical movements which may be divided into three classes, viz.:

1. Heaving, i. e., vertical up and down movement of the ship bodily.
2. Pitching, i. e., swinging about a transverse axis so that the ends of the ship move up and down.
3. Rolling, i. e., swinging about a longitudinal axis so that the sides of the ship move up and down.

All periodical movements are accompanied by forces of acceleration and retardation, whose effect upon the human organism is more or less unpleasant, and all the movements mentioned are therefore apt to cause

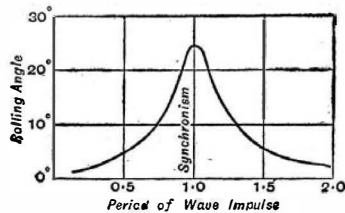


FIG. 1.

sea-sickness more or less, in accordance with their character, their magnitude and their frequency.

Heaving motion is unavoidable with ships designed to float on the surface of the water and therewith on the surface of waves. Submarines are naturally less liable to heaving, as the wave motion decreases with the distance from the surface of the water, but compared with such a mode of traveling, probably heaving will appear as the smaller evil. The range of motion, according to the height of sea waves, is not infrequently 20 feet, and sometimes may exceed even 30 feet, but fortunately the frequency or the period in such cases is not high, and with shorter periods the amplitudes are proportionately smaller, so that in either case the accelerating forces do not exceed certain limits. Furthermore, the pure heaving motion, with the decks keeping horizontal, seems to have comparatively little effect upon the human frame, and observations show that considerable amplitudes are satisfactorily borne by most people. This is, perhaps, the reason why heaving is so rarely mentioned as a cause of sea-sickness.

Pitching is considerably more dreaded, and the movement is undoubtedly most unpleasant at the ends of a vessel, considering that the period of pitching is generally very short, and one may be pitched over 30 feet up or down within two to three seconds. But pitching has the relieving feature that its effect can be evaded, almost entirely, by staying amidships, where the vertical movement due to pitching is naturally nil; the remaining angular movement does not often exceed 4 degrees to each side, and is, therefore, immaterial in comparison with rolling, where not infrequently angles of five times that amount are recorded.

In rolling, two movements should be distinguished, viz., the vertical movement at the sides of the vessel, and the much more disagreeable angular movement

and especially those people who have avoided altogether the sight of the dining-tables on such occasions, will not long for a similar experience. The general wish, under such conditions, is that the rolling should stop, and probably there is sometimes an indistinct hope that some mysterious power could appear and hold the ship steady. This power has now appeared with Dr. Schlick's invention of his gyroscope for preventing ships from rolling.

Prevention is to be distinguished from reduction of rolling. Various appliances have been devised for the latter purpose, so for instance the bilge keels,

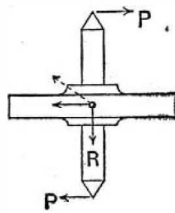


FIG. 2.

now almost generally applied, form a simple expedient for reducing rolling to some extent. But as their effect depends upon the water resistance set up against the rolling motion itself, considerable angles of roll must necessarily remain under all conditions, in order to produce an effect, and therefore nothing but a moderate reduction of rolling can be expected from bilge keels in practice. The same applies to rolling tanks and other appliances whose action depends upon the existence of large rolling angles.

To prevent rolling it has to be stopped at the root so to speak; and to understand fully how this is accomplished by Dr. Schlick's gyroscope we must first understand how rolling arises. Closely connected with this problem is the well-known fact that some vessels show a great tendency to rolling while others hardly ever roll at all.

A vessel in still water when forcibly heeled over and then suddenly released behaves like a pendulum, viz., carries out a number of oscillations about its upright position, which decrease gradually in their amplitude but succeed each other in equal intervals of time. This constant time interval, called the natural period of the vessel, depends to a great extent upon the metacentric height of the vessel, and is therefore a factor of the design, so that the naval architect is enabled to give the ship a long or a short period as may be required. The period is of great importance in a seaway in connection with the periodical movements forced upon the ship by the impulse of the waves.

The waves passing underneath a vessel tend to incline it so as to bring the decks in parallel with the effective wave slope. If the waves are not met in quick succession, the movement actually taking place will be very small, from want of time. Further, if the waves are met very slowly, the ship will have time to follow the wave slope closely, and the maxi-

sufficient water and air resistance, which absorbed the energy added to the swinging vessel by every fresh wave impulse. Naval architects are paying due attention to this problem, and the factor of safety in modern ships is so great that cases of overturning through excessive rolling are almost unknown.

Nevertheless, the rolling angle accumulated at or near the period of synchronism is usually many times larger than the maximum effective wave slope producing it. To illustrate the relative tendency of a vessel toward rolling under the conditions mentioned, Fig. 1 has been prepared; it represents the maximum

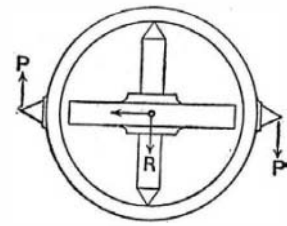
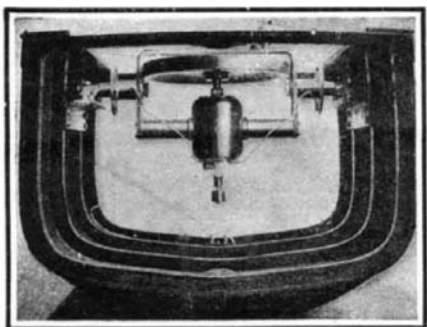


FIG. 3.

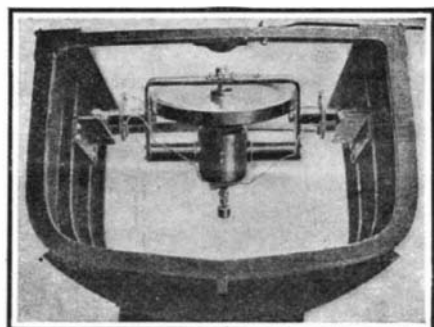
rolling angles which could be accumulated by waves, all of the same height, but meeting the vessel at different time intervals or periods. The curve applies to an actual ship ("Seebar"), and has been derived from various observations; further investigations show that other vessels would yield curves more or less similar in character. Fig. 1 indicates that by far the greatest rolling angles occur at or near the period of synchronism, at higher or lower periods the angles become rapidly smaller. It is therefore obvious that rolling can be avoided, to a great extent, by avoiding synchronism.

The possibility of avoiding synchronous rolling was recognized many years ago, when observations had shown that the actual periods of wave impulse, generally met with at sea, are comparatively short and can be greatly exceeded by the ship's period, if the metacentric height is kept sufficiently small. But although this has been frequently pointed out by leading naval architects, there are still many ships afloat with too short a period, so that heavy rolling is frequent with them. Others are much less liable to roll, as mentioned above, and it is likely that further improvements can and will be made in this direction; yet, however long the period of a vessel may be, the chances of synchronism and therewith the chances of heavy rolling still exist, especially with a quarter sea.

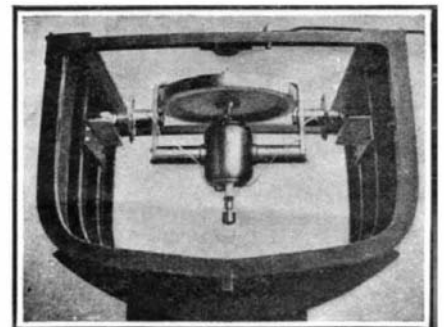
To deal with such cases as these, i. e., to prevent rolling under any conditions of sea, but especially under the conditions of synchronism, is the object of Dr. Schlick's gyroscope. The apparatus consists principally of a heavy flywheel rotating at a considerable speed, and supported in such a way that any tendency of a wave to heel the vessel over sets up gyroscopic forces in the apparatus, which practically counterbalance, at every instant, the effect of the wave, and thus prevent the ship from rolling.



THE GYROSTAT IN VERTICAL POSITION.



THE GYROSTAT TILTED FORWARD.



THE GYROSTAT TILTED BACKWARD.

## PRACTICAL TESTS OF THE SCHLICK GYROSTAT FOR SHIPS.

which equally affects all parts of the ship, and therefore cannot be evaded. Small angles up to about 5 degrees to each side are of little consequence, but the effect of angles over 10 degrees or even 20 degrees, is not so easily forgotten; and people who have experienced real rolling of this description, who have felt the discomfort of moving about on board a ship when the level of the decks is changing incessantly from side to side, who have seen dishes, plates, vegetables, etc., sliding and rolling about the dining-table,

the angle of roll will be equal to the maximum effective wave slope, which is generally moderate. Serious rolling is, however, almost certain, even in a comparatively light sea, when the waves are met at such regular intervals as correspond with the natural period of the vessel, or in other words, when synchronism exists between the period of the wave impulse and the natural period of the vessel. In such cases the rolling angle gradually becomes larger with each wave, the rolling is accumulative, and with perfect synchronism the angle would become infinite, i. e., every ship would turn turtle if it did not encounter

To avoid misunderstanding, it may be pointed out that these forces, set up in the apparatus, are active forces and must not be confounded with ordinary dead resistances, which would be offered by the ship, if it was kept absolutely rigid, as for instance on a rock. It must also be mentioned, that the steadying effect is not merely due to the presence of rotating masses, so for instance, steam turbines in a vessel or even Schlick's apparatus under certain conditions, as will be shown later, have not the slightest effect upon the rolling. To explain these and other phenomena, connected with the present problem, a brief investigation

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regarding the origin of gyroscopic forces will be necessary.

Suppose a wheel or disk (Fig. 2) be rotating so that the mass element or particle at the front side of the circumference would move toward the left, as shown by the full-drawn arrow. The forces  $PP$ , tilting the axis of rotation, tend to bring the particle into a new direction of movement shown by the dotted arrow, and it is evident that the resistance offered by the

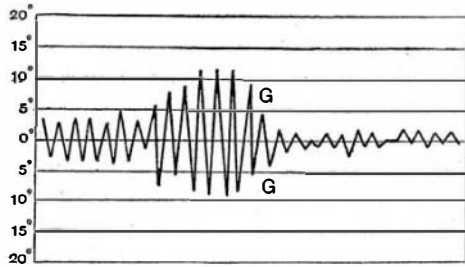


FIG. 5.

particle against this change will be downward as indicated. As the particle passes on, others will appear in its place, and the resistance,  $R$ , will consequently last as long as the tilting movement of the axis continues in the indicated direction,  $PP$ . A similar consideration shows that the same tilting movement causes particles passing through the opposite position at the back of the circumference, to offer resistance upward. Particles at both sides of the circumference do not change their direction of movement and, therefore, offer no resistance against the tilting of the axis. Partly one and partly the other of the three conditions mentioned applies to all the intermediate mass particles, at the circumference of the disk as well as anywhere inside. All the front particles exert gyroscopic forces downward, and all those in the back of the disk upward, their combined effect being a resisting movement or couple whose axis is at right angles to the axis of the tilting movement,  $PP$  (compare Fig. 2). A strict mathematical investigation shows that this couple increases in direct proportion with the angular velocity of tilting, with the speed of rotation, and with the inertia moment of the rotating mass.

All these facts can be corroborated by experiment and some by observation in practice. So for instance, on a paddle steamer the following phenomena can be observed:

1. If the course is suddenly changed, the vessel heels over.
2. If the vessel is heeled over, say, by a wave, the course is slightly altered.

These phenomena are largely due to the gyroscopic action of the paddle wheels, but, owing to the small rotary speed of these wheels, the effect is generally so slight that it is not easily noticed. To show these phenomena much more clearly, a model has been designed, in which the two paddle wheels are represented by solid disks revolved at a high speed by means of a small electric motor. The little vessel is so supported that it can heel over to either side and turn freely about a vertical axis. It is noticeable, with the wheels revolving, that a slight turning of the bows to starboard causes the vessel to heel over to port, and convertibly. Further, if the vessel is heeled over by a small weight added to one side, it starts to turn and alter its course; for instance, by heeling over to starboard the ship's bow is turned to starboard. It is rather curious that this should take place in practice, as the starboard paddle would be deeper immersed, when the vessel is over to starboard, and would, therefore, tend to turn the vessel in the opposite direction, i. e., to port. Yet the phenomenon was observed by Dr. Schlick some years ago and has induced him to a closer study of this problem and of gyroscopic problems generally; the result of these studies was the invention of the gyroscope which forms the subject of this paper.

A further example for demonstrating gyroscopic forces is the portable gyroscope, consisting of a flywheel mounted in a circular frame; when set spinning it can be moved about with its axis parallel, without offering any appreciable resistance; but gyroscopic forces can be distinctly felt with this apparatus when holding it in two hands and producing the necessary tilting movement; it can also be noticed that this strange resistance does not act in the direction of the movement, but in a plane at right angles to the intended tilting movement. This latter fact, which coincides with the preceding investigations, goes to show that a gyroscope like this, if fixed in a ship, could not resist any impulses of the waves, because the gyroscopic forces produced would always be at right angles to the forces of the waves, and could, therefore, have no steadying influence. The same argument applies to any other rotating mass on board a ship, as steam turbines, paddle wheels, etc.; and no steadying power can be expected from these, because their axis of rotation is fixed in the ship, and therefore practically immovable in certain directions.

That the effect is *nil* under these conditions, can easily be judged by the movement of this model pendulum, which has a gyroscope of the preceding type attached to it. The pendulum swings with a certain period when the flywheel is at rest, and the experiment shows that the movement is exactly the same after the flywheel has been set spinning. It is, therefore, evident that something more is required for creating those forces which are necessary for preventing ships from rolling.

Fig. 3 shows the flywheel placed in a frame, which is held in bearings at the right and left, so that it can swing about this horizontal axis. The forces,  $PP$ , acting now upon the frame, and tilting it in the direction indicated, create gyroscopic forces,  $R$ , as has been explained in connection with Fig. 2; viz., the forces,  $R$ , are directed downward in the front parts of the wheel, and upward in the back. The same rule applies, if we look at the wheel from the left-hand side, and assume that the frame be tilted by the forces,  $R$ . As the direction of the movement is in every way the same as in the previous case, the gyroscopic forces set up by the new tilting movement will again be downward in front of us, that is at the left side of Fig. 3, and upward at the opposite side, forces which are evidently both opposed to the original forces.

The arrangement shown in Fig. 3 is consequently able to oppose tilting or angular movements, as may be further demonstrated by our pendulum apparatus. It will be remembered that the swinging movement of this model pendulum was not in any way modified by the gyroscope attached to it. The reason for

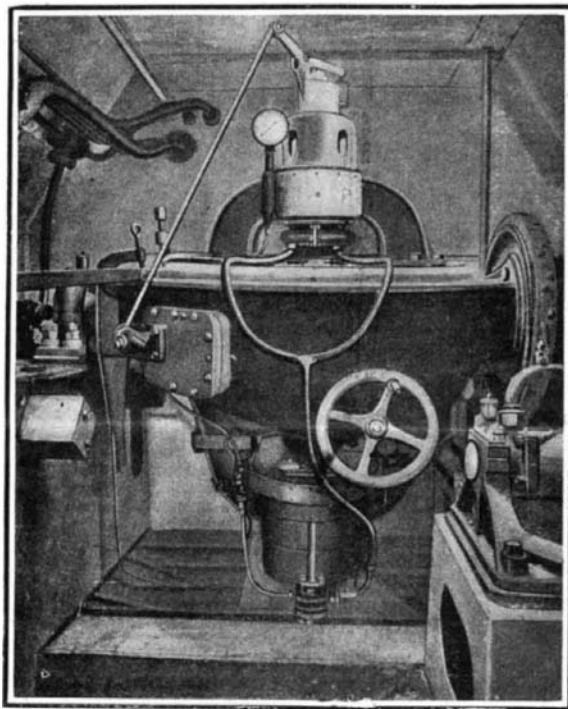


FIG. 4.—THE SCHLICK GYROSTAT IN THE "SEEBAR."

this was that the gyroscope frame had been prevented from swinging and consequently from acting upon the pendulum, as will be obvious from the explanations given. If now the frame is released and left free to swing, it will be noticed that the same pendulum is very much slower in its period; because it is practically held steady in its extreme positions for a short interval of time, until the gyroscope has finished its full swinging movement of about 180 degrees, and therewith exhausted its resisting power.

It will further be noticed that, although the pendulum is retarded each time, and its period is thereby lengthened, the amplitude does not decrease, and consequently, if such a gyroscope was applied to a ship and any appreciable roll did appear, the apparatus

in Schlick's gyroscope, viz.: (1) The general arrangement of the apparatus; and (2) the brakes.

The general arrangement is shown diagrammatically in Fig. 3. The axis of the flywheel may have any position transversely to the ship, but provision must be made that it automatically returns to this position, in order to produce the best results. The axis of the

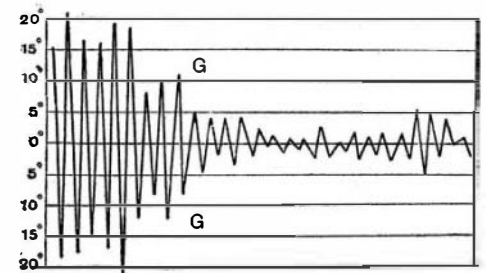


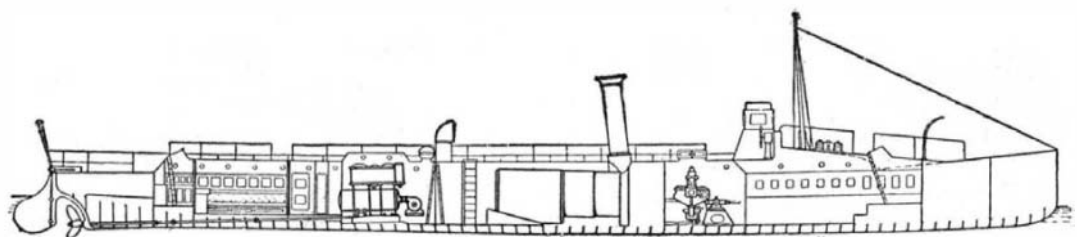
FIG. 6.

oscillating frame is also placed transversely in the ship, but at right angles to the above normal position of the flywheel axis, whose ends move in the fore and aft direction when the frame is swinging. These conditions are fulfilled in the two pendulum models here exhibited, whose vibrations may represent the rolling motion of a vessel. In one of the pendulums the axis of the flywheel is originally vertical; in the other one it is horizontal, and the experiment shows that both gyroscopes behave in a similar manner, and increase the period of the pendulum equally well. But preference is generally given to the arrangement where the forces of gravity can now be employed for returning the flywheel axis to its original position, which simplifies the design.

As mentioned above, the brakes form another important feature of Schlick's apparatus and cannot be dispensed with. The small models exhibited were the gyroscope fitted in the small vessel which is floating in the small tank and the other apparatus (Fig. 4) applied to one of the sections of a vessel, have both friction brakes, which are always in action, and therefore readily extinguish any angle of heel given to the models in question. For larger machines the brakes are more elaborate, they are either hydraulic or friction brakes, and generally so designed as to meet the varying conditions of sea automatically, and to safeguard the gyroscope apparatus against overloading.

This second model further shows that the gyroscope offers no resistance against rolling, if the frame is tilted so far, that the axis of the flywheel becomes horizontal. This is due to the obvious fact that in this position, viz., with the flywheel axis in the fore and aft direction, no resisting couples can be transmitted through the axis in the direction of rolling. The resistances are necessarily vertical to the flywheel axis and, therefore, only a component of these resistances is useful in preventing rolling; at 90 deg. deflection of the gyroscope frame the component becomes zero, as already explained. Should the frame swing further than 90 deg., the tendency of the apparatus would be again to prevent rolling, and even an overturning of the gyroscope as shown by this model, would not reverse its action. Practical considerations, however, lead to the adoption of a limit for the swinging motion, and stops are generally provided to arrest the frame, before an angle of 90 deg. to each side is reached; such stops are existing at angles of 45 deg. in the small tank model.

Another appliance generally fitted is a brake, or other suitable device, for holding the gyroscope frame in a fixed position, and thereby suspending the action of the apparatus, even with the wheel rotating, as previously explained. Both the models described here have such appliances, and the experiment



LONGITUDINAL SECTION OF THE "SEEBAR," SHOWING GYROSTAT FORWARD.

#### PRACTICAL TESTS OF THE SCHLICK GYROSTAT FOR SHIPS.

would not be able to extinguish it. And naturally so, because the apparatus has no means yet for absorbing any of the energy contained in the vibrating system. To remedy this, Dr. Schlick applies brakes to the swinging movement of the gyroscope frame, and as the small friction brake of this pendulum apparatus is brought into action, the movement of the pendulum is quickly extinguished. (Shown by experiment.)

There are consequently two outstanding features

shows that, with the apparatus thus put out of action, considerable rolling angles can be quickly accumulated by applying a comparatively small weight eccentrically in regular intervals, as would correspond with the action of synchronous waves. But when the apparatus is put into action by removing the clutch that holds the frame, and the same weights are applied in similar intervals as before, the vessel remains practically steady, the residuary angle of roll required for the working of the apparatus being hardly percep-

tible, and only the gyroscope is seen swinging to and fro. This is very similar to the working of larger gyroscopes on board a ship at sea, and careful investigations have shown that a properly designed apparatus is able to adjust its movements so quickly, that equilibrium with any external moment is generally established within the fraction of a second, and all the irregularities of the wave impulses are followed by the machine with an astounding accuracy. It is therefore perfectly certain that rolling can be practically prevented by a well-designed apparatus of sufficient size.

What size the apparatus ought to be for a certain size of vessel, under the conditions of sea met with in practice, has been early recognized by Dr. Schlick as the vital question of his invention. He also realized that only experiments on a large scale could bring this problem nearer to its solution. He therefore purchased a suitable vessel, a German torpedo boat, and fitted it out with a gyroscope of comparatively large size. The steamer is 117 feet long, 12 feet 6 inches broad, and displaces 65 tons on a draft of 3 feet 10 inches, the metacentric height is 1.3 feet, and the natural period of rolling about 2.1 seconds from side to side. The gyroscope wheel is driven by steam, turbine blades being fixed on its circumference. The frame of the gyroscope is represented by the steam-tight cast-iron casing, receiving and exhausting the steam through the trunnions on which the gyroscope oscillates. The diameter of the steel flywheel is about 39 inches, and its usual speed of rotation about 1,600 revolutions per minute. The hydraulic brake for controlling the oscillatory movement of the frame consists of a cylinder with a piston forcing the fluid through a valve, the opening of which can be regulated from the deck. The arrangement for putting the apparatus out of action consists of a friction band brake, also operated from deck, by which the gyroscope frame or casing can be held in a fixed position or released as may be required.

The experiments carried out with this apparatus by Dr. Schlick yielded most satisfactory results, and it was found that the vessel could be kept steady in a sea which produced rolling angles up to 20 deg. to each side with the apparatus out of action. Fuller details of these trials are given in a paper read by Sir William H. White before the Institution of Naval Architects in 1907.

The success of these experiments has induced Messrs. Swan, Hunter and Wigham Richardson, Ltd., of Wallsend and Walker on Tyne, to acquire from Dr. Schlick the patent rights for the British Isles, France, and America, including the experimental vessel "Seebär," which is now generally called "Seebar."

Further trials have been carried out with this vessel recently off the Tyne, in the open sea. Dr. Schlick's experiments were made in the lower Elbe, and his greatest cause of complaint and disappointment used to be that the surface of the water was generally not sufficiently rough for the intended rolling trials. Such disappointments were hardly ever met with in the experiments off the Tyne, and even in moderate weather the sea was rough enough to toss the "Seebar" about violently. But the drawback was that the waves were generally so irregular in length that the condition of synchronism could seldom be far enough approached for accumulating a large rolling angle without, and thus the apparatus could not be shown to its best advantage. Nevertheless, the steadying effect was marked under all conditions of sea met with, and could be felt distinctly by everybody on board; so that the visitors who witnessed some of these tests, viz., representatives of various steamship companies and others, were generally convinced within a few minutes that by turning a certain wheel on deck, and thereby putting the gyroscope into action, the rolling could be stopped almost immediately, and further rolling could be prevented until the same wheel was turned in the opposite direction and thereby the action of the gyroscope again suspended.

Some of the results obtained during the various trials are reproduced in Figs. 5 and 6, showing the consecutive rolling angles to port and starboard. The left-hand part of the diagrams represents the rolling observed without the gyroscope in action; at G the gyroscope frame was released and the apparatus began to act, with the results indicated in the diagrams. A small angle must necessarily remain to overcome the initial friction of the apparatus; this angle is as a rule negligible, as in Fig. 5, and we may say that rolling is practically prevented as long as the gyroscope is in action. The diagram, Fig. 6, has been obtained in a much higher sea with occasional very steep waves, which have evidently not been fully mastered by the apparatus, as on one occasion the remaining angle of roll exceeds five degrees to one side;

however, the results may still be called satisfactory.

The experiments have shown that the "Seebar" is kept sufficiently steady when either drifting or steaming in a sea of about five feet average height, with occasional waves up to eight feet high. This result is very encouraging with regard to the application of gyroscopes to large vessels working in comparatively longer and higher waves, and it may be reasonably expected that a wheel about 6 feet in diameter, running at 1,400 revolutions per minute, would keep a vessel of 2,000 tons displacement, with a moderate metacentric height, steady in any sea that is likely to be encountered. The metacentric height is of first importance, as the size of the machine increases very much with the item. In steam yachts, pleasure and Channel steamers, which come principally in question for the application of gyroscopes, the metacentric height can be kept small, and, in any well-designed vessel, is kept as small as possible, on account of the advantages pointed out above, but there seem to be still many ships afloat where not enough attention has been paid to this important matter.

The first practical application of Schlick's gyroscope will be made in Germany. The Vulcan Works in Stettin have recently finished the apparatus intended for the Hamburg-America Company's vessel "Silvana," a pleasure steamer of about 900 tons displacement. This gyroscope is steam-driven and similar in design to that on the "Seebar;" the flywheel is 63 inches in diameter, and designed to run 1,800 revolutions per minute. The shop tests carried out with this machine a few weeks ago have given entire satisfaction, and the apparatus will begin its duty at sea very shortly.

The Tyneside Company have also commenced the manufacture of Schlick's gyroscopes at their Neptune Works. The design of their machines is somewhat different from the above. The flywheel is driven by an electric motor fitted on the same shaft. The brakes are not hydraulic, but friction brakes of a special design, and various other modifications have been introduced in order to produce standard machines of a compact, simple, and efficient type.

One apparatus for a pleasure steamer of 500 tons displacement is now nearly completed, and it is expected that, in Great Britain as well as in Germany, ships fitted with steadying apparatus will be in service very shortly.

# MODERN THEORIES OF ELECTRICITY AND MATTER.\*

BY MADAME CURIE.

WHEN one reviews the progress made in the department of physics within the last ten years, he is struck by the change which has taken place in the fundamental ideas concerning the nature of electricity and matter. The change has been brought about in part by researches on the electric conductivity of gas, and in part by the discovery and study of the phenomena of radioactivity. It is, I believe, far from being finished, and we may well be sanguine of future developments. One point which appears to-day to be definitely settled is a view of atomic structure of electricity, which goes to conform and complete the idea that we have long held regarding the atomic structure of matter, which constitutes the basis of chemical theories.

At the same time that the existence of electric atoms, indivisible by our present means of research, appears to be established with certainty, the important properties of these atoms are also shown. The atoms of negative electricity, which we call electrons, are found to exist in a free state, independent of all material atoms, and not having any properties in common with them. In this state they possess certain dimensions in space, and are endowed with a certain inertia, which has suggested the idea of attributing to them a corresponding mass.

Experiments have shown that their dimensions are very small compared with those of material molecules, and that their mass is only a small fraction, not exceeding one one-thousandth of the mass of an atom of hydrogen. They show also that if these atoms can exist isolated, they may also exist in all ordinary matter, and may be in certain cases emitted by a substance such as a metal without its properties being changed in a manner appreciable by us.

If, then, we consider the electrons as a form of matter, we are led to put the division of them beyond atoms and to admit the existence of a kind of extremely

small particles, able to enter into the composition of atoms, but not necessarily by their departure involving atomic destruction. Looking at it in this light, we are led to consider every atom as a complicated structure, and this supposition is rendered probable by the complexity of the emission spectra which characterize the different atoms. We have thus a conception sufficiently exact of the atoms of negative electricity.

It is not the same for positive electricity, for a great dissimilarity appears to exist between the two electricities. Positive electricity appears always to be found in connection with material atoms, and we have no reason, thus far, to believe that they can be separated. Our knowledge relative to matter is also increased by an important fact. A new property of matter has been discovered which has received the name of radioactivity. Radioactivity is the property which the atoms of certain substances possess of shooting off particles, some of which have a mass comparable to that of the atoms themselves, while the others are the electrons. This property, which uranium and thorium possess in a slight degree, has led to the discovery of a new chemical element, radium, whose radioactivity is very great. Among the particles expelled by radium are some which are ejected with great velocity, and their expulsion is accompanied with a considerable evolution of heat. A radioactive body constitutes then a source of energy.

According to the theory which best accounts for the phenomena of radioactivity, a certain proportion of the atoms of a radioactive body is transformed in a given time, with the production of atoms of less atomic weight, and in some cases with the expulsion of electrons. This is a theory of the transmutation of elements, but differs from the dreams of the alchemists in that we declare ourselves, for the present at least, unable to induce or influence the transmutation. Certain facts go to show that radioactivity appertains in a slight degree to all kinds of matter. It may be, therefore, that matter is far from being as

unchangeable or inert as it was formerly thought; and is, on the contrary, in continual transformation, although this transformation escapes our notice by its relative slowness.

In the beginning of the last century Coulomb and Ampère regarded each of the two kinds of electricity to be a fluid under the influence of central forces—repulsion existing between particles of the same fluid and attraction between particles of different fluids. Such forces would be proportional in the electric charge of the particles, and would vary in inverse ratio to the square of the distance between them. Starting with these hypotheses, and explaining suitably the observed facts relative to the different nature of conductors and dielectrics, they constructed a very perfect theory of electrostatic phenomena. An analogous theory for magnetism may be built up by assuming that the law of action between two magnetic poles is absolutely like the law of action between electrified particles. The electric current was regarded as the flowing of an electric fluid in a conductor. To establish a theory of electro-magnetics and electro-dynamic phenomena, it is necessary to bring in a third law of action-at-a-distance between the magnetic poles and the electric-current law of Laplace. All these theories in their entirety are founded on the laws of forces acting at a distance, in combination with the conception of electric fluids.

Faraday, although contemporaneous with this development, looked at the question from a different point of view. He did not believe in the possibility or power of action-at-a-distance between electrified bodies, and thought that the forces which were exercised between them resulted from elastic tensions which established themselves in the intervening medium. These elastic forces comprise a tension in the direction of the lines of force and a pressure at right angles to them. In seeking to show the direct influence of the medium he was led to the discovery of the inductive power of dielectrics, and his belief in the essential

\* Abstracted from a lecture. Translated, by permission, from *Revue Scientifique*, Paris. Fifth series, Nos. 20, 21, Vol. VI., November 17 and 24, 1906.