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between disinfecting power and degree of dissociation [1]), formerly studied by PAUL and KRÖNIG. Antitoxic actions of metal on metal with animal cells as reagent, studied by LOEB, proved however that the explanation cannot always be sought in this direction [2]). So a deeper interpretation of the case here mentioned must be put off for the present, the more as, very likely, it will appear not to belong to the domain of physiology but of chemistry.

The observations may be completed with the results of some experiments with other compounds.

The toxicity of chinine hydrochloride for potato and for sugar-beetroot is as clearly as by NaCl diminished by KBr, LiBr, $Ca(NO_3)_2$, which are rather different salts. Glucose and saccharose, on the other hand, have no influence whatever.

Also of another organic poison, namely oxalic acid, the action proved to be partially neutralised by NaCl being also present in the solution. Especially the sugar-beetroot gave very distinct results here, although also with the potato the antitoxic influence of the salt was clear. In a less degree, but yet in an unmistakable manner, the toxicity of oxalic acid is counteracted by saccharose.

Some experiments with a metallic poison (cupric salts) gave results which were in general concordant with those of KAHLENBERG and his collaborators.

Physiology. — "*On some applications of the string galvanometer*". By Prof. W. EINTHOVEN. Communication from the Physiological laboratory at Leyden.

In a former paper [3]) the amount of sensitiveness of the string galvanometer and the time in which the deflections of the quartz-thread are accomplished were mentioned and illustrated by a few photograms. We stated that with a feeble tension of the wire a current of 10^{-12} Amp. could still be observed and that with a stronger tension, so that the movement of the wire is still dead-beat and the sensitiveness is reduced to a deflection of 1 mm. for 2×10^{-8} Amp., a deflection of 20 mm. requires about 0.009 seconds.

1) Zeitschr. für physikal. Chemie. Bd. 12. 1896. Zeitschr. fur Hygiene. Bd. 25. 1897.

2) PFLÜGER's Archiv. Bd. 88. 1901. Americ. Journ of physiol. vol. 6. 1902

Other observations belonging to the same category of animal physiology, were recently made by E. LESNÉ and CH. RICHET FILS, (Arch. internat. de Pharmacodynamie. XII. 1903).

3) These Proc. June 27. 1903. p. 107.

These data may be sufficient to form an opinion about the instrument in theory and to give an idea of its fitness for practical work; yet on this latter point the applications alone can give full and convincing evidence.

In what follows we intend to mention some of these applications.

Where the object is to measure very feeble currents no other galvanometer seems to equal the instrument we are considering. It is obvious that theoretically there is no limit to the sensitiveness of any arbitrary galvanometer for constant currents. One can indefinitely increase the period of oscillation of the magnets as well as the distance of the scale and so obtain any desired sensitiveness in theory. But practical difficulties soon draw a limit. One among other difficulties is the inconstancy of the zero-point, which is influenced by many circumstances and which causes the more trouble the more the period of oscillation increases.

This is probably the reason why an electrometer is preferred to a galvanometer when very feeble currents have to be measured, e. g. when great insulating resistances have to be examined or the ionising power of radio-active substances.

In the celebrated investigation by Mr. and Mrs. CURIE [1]), which led to the discovery of radium, the radio-activity of various materials was judged by their power to render air conductive; and the conductivity of the air was measured by means of an electrometer. The electrometer had to be charged by a current, which passed through a conducting layer of air, the rate at which the electrometer was charged being a measure for the current.

Evidently it was not an easy matter to measure currents in this way; so Mr. and Mrs. CURIE preferred a method of compensation by means of a rod of piezo-electric quartz. The charge received by the electrometer through the layer of conductive air was compensated by a contrary charge derived from the quartz-rod. To effect this the rod was subjected to a steadily increasing pull by continuously adding weight to a scale suspended on the quartz-rod. In this way the image of the mirror of the electrometer had to be kept at zero, the increase of the pull during the time being the measure for the current and in this case also for the conductivity of the air.

It is much easier to make these measurements with the string galvanometer.

I connected the instrument with two brass plates A_1 and A_2, fig. 1.

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1) See e.g. Mme SKLODOWSKA CURIE, Recherches sur les substances radioactives. Annales de Chimie et de Physique 7, T. 30, p. 99, 1903.

Both plates were round, had a diameter of about 25 cm., were insulated and mounted at a distance of about 2 cm. from each other; the laboratory-battery of about 60 Volts and a resistance of 1 Megohm were inserted in the circuit from the galvanometer G to the plates.

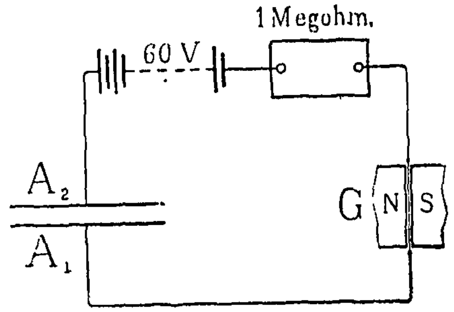

Fig. 1.

The sensitiveness of the galvanometer was adjusted at 1 mm. deflection for 2×10^{-11} Amp., the time required for a deflection being about 5 to 7 seconds. Now a round plate, covered over a diameter of about 20 cm. with powdered uranium-trioxide (containing water) was shoved in between A_1 and A_2 and laid on A_1. The galvanometer now showed a deflection of 2.5 mm. As soon as the uranium-preparation was removed it pointed exactly zero again.

The uranium-preparation was in this way repeatedly brought between the plates of the condenser and taken away again and each time the galvanometer showed the same deflection of exactly 2.5 mm. Each measurement was made in from 5 to 7 seconds; since, as has been shown before, a deviation of 0.1 mm. can still be noticed, the probable error of the observations may be put at 4 per cent.

The current measured amounted to 5×10^{-11} Amp., a value of the same order as that calculated by Mrs. CURIE for other uranium-compounds which had been examined under similar circumstances by means of the piezo-electrometer.

We will briefly mention some experiments with a few milligrams of a radium-salt. When the radium was placed between the condenser plates, a P. D. of 2 Volts proved sufficient to deflect the image of the wire a few centimetres. With a P. D. of 40 Volts in the circuit the same effect could be obtained by holding the radium-preparation at a distance of 1 metre from the plates. A definite distance of the radium from the plates corresponded to a definite indication of the galvanometer and it was obviously easy to drive the image from the scale by approaching the radium. It was remarkable in all these experiments that when the preparation of uranium or radium was not moved, the deflection of the galvanometer also remained steady.

These observations also show how easy it is to measure an insulating resistance with the string galvanometer. The experiment with the uranium-trioxide showed that the resistance of the layer of air between the two plates of the condenser amounted to $\frac{60 \text{ Volts}}{5 \times 10^{-11} \text{ Amp.}} = 1.2 \times 10^{12}$ Ohms or rather more than a million Megohms. An insulating resistance of 6×10^{13} Ohms can be demonstrated with the 60 Volts laboratory-battery by a lasting deflection.

We finally mention another application of the string galvanometer for measuring very feeble currents, namely those which are caused by atmospheric electricity. A spirit-lamp is held up on a long pole in the open air. An insulated wire connects the flame with one terminal of the galvanometer-wire, the other terminal being earthed. Under these conditions one sees a lasting deviation of the galvanometer which diminishes and disappears as soon as the pole is lowered and carried indoors, but which returns as soon as it is taken out and held up again.

The deflection of the galvanometer in these experiments was generally more or less oscillating on account of the wind causing fluctuations in the contact of the flame and the end of the wire.

Besides for measuring feeble currents, the wire-galvanometer is suitable in practical work for detecting small quantities of electricity and especially for accurately measuring rapid variations of electric tension or of feeble electric current. As the instrument for feeble currents which is quickest in its indications, it will undoubtedly prove useful for transoceanic telegraphy.

The smallest quantity of electricity that can be detected by it, can easily be calculated. Let us imagine that a great resistance has been inserted in the circuit so that the electromagnetic damping of the moving wire may be neglected and that now suddenly a current of constant intensity is sent through the wire.

The movement of the wire under these circumstances is accurately represented in the formerly published photograms [1]). Theoretically the wire will, at the moment the current starts, experience an electromagnetic force by which an acceleration will be imparted to it. Its motion will be an accelerated one until a speed is attained such that the resultant of the electromagnetic force and the tension of the wire will make equilibrium with the resistance of the air.

1) These Proc. June 27, 1903, p. 107.

If however the tension of the wire is feeble enough, the duration of this accelerated motion is very small compared with the total duration of the deflection so that it may be neglected. We are then allowed to speak of an initial velocity of the wire and may disregard its mass. The initial velocity is proportional to the current and may be estimated at about 20 mm. per second for a current of 10^{-9} Amp. with an image as is obtained with our magnification [1]).

A current then of 10^{-9} Amp. only needs to last for $\frac{1}{200}$ sec. to cause a deviation of 0.1 mm. and as the photograms prove such a deviation to be still visible, a quantity of electricity of 5×10^{-12} Ampère-seconds can consequently be detected. This quantity is equal to the charge of a condenser of 1 microfarad at a potential of 5×10^{-6} Volts or to the charge of a sphere of 4.5 cm. radius at a potential of 1 Volt.

Since, as was pointed out above, the initial velocity is proportional to the current, the deflection for a small quantity of electricity, will entirely depend on that quantity itself, and it will make no difference whether a strong current passes during a short time or a feeble current during a longer time, if only the time of passage be small enough.

The properties of the wire-galvanometer lead us to expect another very remarkable consequence. If the tension of the wire is increased, the velocity with which a deflection is accomplished, will increase, but at the same time the amount of the deflection for a given current will diminish. Now it has already appeared from the photograms that, *provided the tension of the wire is not too great*, the change in sensitiveness is exactly inversely proportional to the change in deflectional velocity, so that the initial velocity for a given current is independent of the tension of the wire. From this we derive the seemingly paradoxical result that under the condition mentioned the deviation for a quickly passed, small quantity of electricity is the same for any tension of the wire.

The facts are in complete accordance with this argument and for an observer who is not accustomed to the instrument, it is very curious to see, how with a relatively much greater tension of the wire and a consequent great diminution in sensitiveness for constant

1) This amount of 20 mm. is only approximately true. I hope soon to be able to deal more extensively with the movement of the wire under various conditions. The influence of the viscosity of the air will then be compared with that of the electromagnetic damping. It would be a decided advantage if the wire could be placed in an air-tight space, which would enable us to observe its deflections either in a vacuum or under increased pressure.

currents, the sensitiveness for a quickly passed small quantity of electricity remains nearly unaltered.

And the practical application lies at hand. Whenever rapid variations in electric tension have to be discovered and the disturbance by slowly varying currents has to be avoided, a requirement which frequently imposes itself in electro-physiological investigations, the wire must be relatively strongly stretched.

The described sensitiveness for small and quickly passing quantities of electricity, more even than its sensitiveness for constant currents, makes the wire-galvanometer a suitable research-instrument for a number of phenomena which are usually observed by means of an electrometer.

If one end of the wire is earthed, the other joined to an insulated conductor, e.g. a resistance-box, a rubbed ebonite rod, brought near the resistance-box, will act by influence and easily drive the image from the scale. A single advancing or receding movement of the rod must obviously result in a double movement of the wire, since this latter always returns to zero when the rod stops moving. At a distance of a few metres, rubbing the rod with a silk cloth will still cause deviations of the galvanometer, each single stroke of the hand occasioning a to and fro movement of the wire.

When I had laid aside the ebonite rod and the silk cloth and came near the resistance-box with the hand only, a small deflection of a few millimetres could still be observed. When quickly approaching the hand, the wire showed a momentary deviation in one direction, when quickly withdrawing it, in the opposite sense. Even moving the fingers round one of the plugs of the resistance-box caused the wire to move. It must be emphasised that the resistance-box was not touched by the hand so that ordinary conduction from the body through the galvanometer to the earth was out of the question.

I could not at once explain the phenomenon. My first thought was that the body or at any rate the hand was charged to a certain potential and like the ebonite rod drove electricity by influence through the resistance-box and the galvanometer. But the potential of one of the hands of an uninsulated person is too small to explain the movement of the wire.

Also clothing, e. g. a woollen sleeve, appeared to play no part. If a round metal disk connected to the earth by a conducting wire and hence having presumably the same potential as the galvanometer and the resistance-box, was suddenly brought near or removed from the latter, the same deviations were noticed as when moving the human hand.

Also these deflections changed only little when the metal disk was moved, after having been charged by a storage-cell to a potential of $+2$ or -2.

The idea that the strange phenomenon had to be ascribed to currents in the air which would generate electricity by friction, had to be rejected at once, as soon as, by means of a pair of bellows, a powerful air-current had been directed against the resistance-box without the wire showing the least motion. But in the end the explanation appeared to be very simple. The ebonite plate of the resistance-box has a certain charge and the lines of electric force bend from the ebonite to the metal plugs. As soon as a conductor now approaches, the lines of force are displaced and thus electricity is moved from the metal through the galvanometer to the earth.

That this is the real explanation could be easily shown by rubbing the ebonite of the resistance-box and so charging it to a higher potential. When this was done the deviations became many times larger.

An interesting proof of the usefulness of the wire-galvanometer as a sensitive instrument which at the same time is quick in its indications, is afforded by the ease and accuracy with which it registers sounds.

When a SIEMENS' telephone is connected with the galvanometer, the sound-vibrations falling on the plate of the telephone will send induced currents through the wire, by which this latter will be moved.

As soon as a tone of arbitrary pitch is made to sound against the telephone with constant intensity, the image of the wire broadens in a curious way. In the bright field the narrow, black image is broadened to a band of several centimetres breadth, which has a light grey tint and whose appearance in the field is feebler as it is broader. The middle of the grey band always corresponds to the image of the quartz-thread in rest. The margins have a somewhat darker delineation than the rest of the band.

This appearance is entirely explained by the circumstance that the wire executes regular, rapid vibrations of the same rhythm as the sound-vibrations striking the telephone.

One peculiarity has still to be mentioned. If a sound like *a* or *o* is sung against the telephone-plate, one sees the grey band divided into parts. Symmetrically with respect to the middle of the image, within its real margins something like secondary and tertiary margins are visible which admit of no other explanation than that the motion of the wire, representing the sound in its fundamental and partial tones, consists of a number of vibrations of different frequencies and amplitudes.

We hope soon to analyse this phenomenon photographically. When the intensity of the sound is changed, the breadth of the grey band also changes immediately. And at the moment the sound stops, one sees the narrow, black image of the wire standing perfectly still again in the bright field.

When the telephone is replaced by a microphone and a suitable induction-coil, the same phenomena are observed; with these contrivances however the arrangement has become much more sensitive. Feeble sounds now give rise to considerable broadening and it is surprising to see, how, when one speaks softly at a distance of one or more metres from the microphone, the image of the wire reacts powerfully on each word that is spoken or rather on each syllable that is pronounced, but always immediately occupies its position of rest as soon as the sound stops for a moment.

Feeble sounds, as e.g. the cardiac sounds of a rabbit are excellently rendered by the galvanometer.

Besides for the study of phonetics and of cardiac sounds, the wire-galvanometer will find fruitful applications over an extensive range of physiological research. We already communicated some results of an investigation concerning the human electrocardiogram [1]). Besides, an investigation of the nerve-currents is now in course of progress, about which we will only mention in this place that the action-currents of a nerve, resulting upon simple stimulation, can be shown and registered in an excellent manner. As far as I know action-currents of the ischiadic of a frog, arising by the stimulus at the make and break of an ascending and of a descending constant current, have never been observed hitherto. The string galvanometer shows them in all their details as they must be expected according to PFLÜGER's law of contractions and the existence of which could until now only be surmised from the observed muscular contractions. One also sees the superposition of the phenomena of electrotonus on those of the action-current, which need be no impediment to the interpretation of the obtained curves. We seem to be justified in supposing that perhaps new points of view will be opened about the manner in which the nerve is capable of reacting on various stimuli.

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[1]) l. c.