TOPICS SOMETIMES NEGLECTED IN TEACHING ELECTRICITY.

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Do your students ever have difficulty in calculating the specific resistance of copper? My students never fail to have trouble with this experiment. They can find the resistance of twenty meters of No. 30 copper wire by means of the Wheatstone Bridge, and they have already learned by experiment that the resistance of a wire varies directly as the length and inversely as the area of cross-section. But when they are told to calculate the resistance of a cube of copper one centimeter on an edge, they get badly twisted up. For a time I used to blame myself because of some fancied vagueness in my explanations; but recently I have decided that most of the difficulty lies, not in the method of teaching, but in the queerness of the problem.

The standard of specific resistance, *i. e.*, the resistance of a cube one centimeter on an edge, is about as awkward a unit for practical purposes as the genius of the pure physicist could well invent. The trouble is, not because the metric system is employed, but because the centimeter is too short for a unit of length of wire, and the square centimeter is altogether too large for a practical unit of cross-section. If we feel that we must use the metric system in all experiments, why not take as our unit of specific resistance the resistance of a wire one meter long and one millimeter in diameter?

But I am inclined to go a step farther—in order that we may get a little nearer to the actual method used commercially in calculating resistances—and accept as the standard of specific resistance the “mil-foot.”¹ The resistance of a wire one foot long and one mil (0.001 inch) in diameter is used as the standard almost universally in this country for commercial purposes. Why not use it in the schoolroom? This will make it easier for us to give problems which have about them the smack of real life, instead of the ridiculous sort we sometimes find in problem books,

¹See p. 90 in Jackson's *Elementary Electricity and Magnetism* (Macmillan).

where the object seems to be to test the pupils' powers in arithmetic rather than in physics. Then, too, in some of these problems, why not make use of those very handy wire tables which the wire manufacturers get out? These tables give for the various sizes of wire, according to the Brown & Sharpe gauge, the diameter in mils, area in circular mils, pounds per 1,000 feet, pounds per mile, feet per pound, ohms per 1,000 feet, ohms per mile, ohms per pound and feet per ohm for copper wire at 75° F. With these tables at hand, how easily one can solve an apparently difficult problem, and these are usually the sort that turn up after we get out of school. Even if we do need to calculate a resistance not given in the tables, we can use the same general formula,

$r = g \frac{l}{s}$, letting g = resistance in ohms of one mil-foot, and l = length of the wire in feet, and s = area of cross-section in circular mils. For a copper wire g is approximately 10.5 ohms.

It will be seen that in advocating the use of the methods of electrical engineers I am not sacrificing one whit of the principle involved; I am simply urging that we teach pupils how to do the thing as it is actually being done in business every day.

Another neglected subject is that of FUSES. I suppose we all show our classes that heat is one of the effects of an electric current; how many of us show the effects of an excessive current, or an "overload," and how it is prevented? Then there are many allied questions: What are three or four of the commonest types of fuses? What is their proper position in an electric lighting circuit, or on a power line? What really happens when the "fuse blows out," and what does it look like? About how large is a piece of five ampere fuse wire? These are some of the questions which I find my students ask me, and why not try to answer them by showing them the "real stuff"?

If there is one topic which deserves our attention more than all others, it is the ELECTRO-MAGNET. In what electric machine is it not employed? Yet are we not, most of us, content with a very elementary and qualitative discussion of this subject? Is it not worth while at least to show the meaning and application of the idea of "ampere-turns"? I believe we shall find in the near future

a rational and simple way of teaching such principles as flux density, lines of force per square inch, permeability and hysteresis.

One of the great difficulties we have to struggle against in teaching electricity is the fact that we can not show the pupil a *Volt*, an *Ampere*, or a *Watt*, units of pressure, current and power of that invisible something we call an electric current. This creates an air of unreality about the whole subject, which can be dispelled only by the students' constantly using the unfamiliar idea or term. The inexpensive direct-reading volt-ammeters now on the market have done more to make the terms volt, ampere and watt mean something to secondary school students than anything devised in the way of apparatus for ten years. But while it is easy to use these instruments with our ordinary battery currents, why should we not have in the laboratory at least one standard voltmeter and ammeter, and teach the proper use of these instruments with commercial currents? It is not enough to say that we connect the ammeter in series and the voltmeter in parallel, as most teachers in the engineering schools will testify.

But someone will complain that I am advocating the training of mechanics rather than the training of boys to think and use the fundamental principles of physics. Far from it. I believe in going to the bottom. In teaching the voltmeter and ammeter, I should use the d'Arsonval galvanometer. In fact, I am strongly of the opinion that we must very soon throw aside our tangent and astatic-needle galvanometers, and make use of the excellent forms of the d'Arsonval galvanometers, which are now on the market. This type of instrument combines sensitiveness, compactness, and "dead-beatness." With a d'Arsonval galvanometer and suitable resistances we can easily show the pupil experimentally the fundamental difference in use between the voltmeter and ammeter.

Another subject which seems to me to deserve more attention than it usually gets in our physics course is that of DYNAMOS and MOTORS. It is difficult for us schoolmasters to realize the tremendous importance of dynamo-electric machinery in the industrial world. Should we, therefore, not give a little more attention to this phase of physics than we did ten years ago? In the first place, it seems to me that we can teach the mutual action of a current-

carrying conductor and a magnetic field in such a way that it shall greatly assist the pupil to see directly the fundamental principle of the dynamo and the motor. One very simple way of looking at this phenomenon is as follows:²

Fig. 1.

Fig. 2.

Let Fig. 1 represent the poles of an electro-magnet. The magnetic field between N and S consists of practically parallel lines of force. Fig. 2 represents the cross-section of a wire and the magnetic field about it when the current flows downward, *i. e.*, into the paper. Now, suppose the conductor carrying the current is placed in the space between the polepieces of the electro-magnet. What is the result? We have the superposition of two magnetic fields—one parallel and the other circular—and the resulting magnetic field can be predicted by the law of parallelogram of forces.

Fig. 3.

Figure 3 shows what we actually get by doing the experiment with iron filings. Moreover, we find that the wire, if free to move, does move in the direction indicated by the arrow M. It moves then as if these lines of force were elastic bands and tended to crowd the conductor at right angles across the field. This, then, is the fundamental phenomenon which is made use of in the electric motor.

²See p. 736 in Watson's *Textbook in Physics* (Longmans).

Right here is a good time to teach the use of Fleming's Rule.³ This helps one to remember the direction of motion of the wire, when we know the direction of the flux and the current in the wire, by the use of the first two fingers and the thumb of the left hand.

Following this, it is only a short step to introduce the principle of the dynamo. We have our same magnetic field and conductor; but in this case the conductor is moved by some mechanical force, and the result is that we have a current induced in the conductor which tends to oppose its motion. This is, of course, the so-called Law of Lenz. For example: In the above case, in Fig. 3, if we move the conductor as indicated by the arrow M, the current induced will be in the opposite direction to that indicated in the figure, *i. e.*, it will be outward from the paper. And right here is a good chance to show the meaning and use of the back electro-motive force in a motor.

Nor would I stop with just these fundamental conceptions of dynamo-electric machinery. Why not show the student that the voltage of dynamo depends on the speed, on the number of turns on the armature, and on the flux density between the pole-pieces? In considering this last point, it would be convenient to discuss the magneto-motive force and the reluctance of the magnetic circuit. These are matters which can be demonstrated in the laboratory or on the lecture table, but we can not expect to do it with the cheap toys we sometimes dignify by the name of apparatus.

Then, too, let us by lantern slides or by actual trips to electric plants, give the pupils a glimpse of the real thing as we see it in the modern industrial world.

It is not going to be many years before we shall have to give a really considerable portion of our time in studying electricity to ALTERNATING CURRENTS. We can already show the principle of the alternator, for all our direct current generators are generating alternating currents which have to be rectified by some commutating device. The application of the alternating currents to electric lighting and principle and use of transformers are well within

³See p. 162 in Sheldon's *Dynamo Electric Machinery* (Van Nostrand).

the range of school boys. It is a little harder for the young student to grapple with the problem of the induction motor and the conception of polyphase currents; but that is not so very strange, for these subjects puzzle some of us older heads.

Some years ago I asked a clever electrician, who was engaged in all sorts of electrical construction work, what he thought was the most important principle for the youngster to get hold of in studying electricity, and he said, "OHM'S LAW." Now, I agree with him, if we consider it in all its various forms.

The commonest form which this law takes algebraically is i (amperes) $= \frac{e \text{ (volts)}}{r \text{ (ohms)}}$. But we also need to emphasize the other

forms which this equation takes; namely, $i r = e$, and $r = \frac{e}{i}$. Now, e stands not only for the total E. M. F. in a circuit, but also for the difference of potential between two points in a circuit, and r stands for the resistance between the same two points. Let us not confine ourselves in our problems to cases of batteries, but rather include dynamo circuits. Sometimes we entirely forget the internal drop in potential and speak of the terminal voltage as if it were the total E. M. F. Why not show the application of Ohm's Law in the volt-meter method of measuring high resistances and the volt-ammeter method (so commonly used in shops) of measuring rather low resistances?

If a pupil really has grasped the principle of Ohm's Law, why should he not be able to solve a practical problem like the following (which was recently given to a class in electrical engineering, but which ought to be within the power of secondary school students):

"Sixty storage cells, connected in series, supply current to 100 16 c. p. incandescent lamps, of 220 ohms each, connected in parallel. Each cell has a total E. M. F. of 2 volts and internal resistance of 0.002 ohms. What must be the resistance of the leads between battery and lamps in order that there may be a P. D. of 110 volts at the lamps? What is the total current; the P. D. at the terminals of the battery; the power lost by internal resistance; the power lost in the leads; and power consumed by the lamps? Express the result also in foot-pounds per second."

It would be easy to continue this list of what seem to me neglected points in the teaching of electricity, which is based on

my own personal shortcomings; but my purpose is rather to urge that there may be points in electricity, which usually we have not even mentioned, which would be of real interest to pupils, because they see their application outside the schoolhouse.

Finally, I believe the subject thus presented will yield just as much mental discipline as if it were taught in the time-honored stereotyped fashion with apparatus designed to show the makers' skill in making a seven-in-one apparatus, rather than by apparatus built to illustrate a single point so strikingly as to be immediately useful in understanding the electric machinery of today.

APPARATUS FOR DRAWING HARMONIC CURVES.

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Most elementary text books of physics, in treating of sound, give diagrams illustrating complex wave forms and showing how these are derived from simpler components. Manifestly, if these diagrams are of value it would be much more valuable for the student to see them drawn and actually built up out of simpler curves. It would be still better if he could draw them himself by means of a simple machine. Such an exercise would not be a substitute for the severe quantitative work of the laboratory, but it might even excel that in arousing interest and in helping the student to gain that *familiarity* with fundamental conceptions which is the most important thing in the knowledge of any subject and oftentimes the hardest to secure.

There are various well known pendulum devices for drawing harmonic curves, but these do not seem to have been very generally used, probably because, while very easy to make, they are somewhat tedious to operate, and give readily only curves composed of motions at right angles to each other (Lissajous' figures), which are very pretty, but do not illustrate the subject as well as wave form curves. An evident improvement is to build up trains of geared wheels and, by connecting rods or some other method, to derive harmonic mo-