Electric current similar to water current

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Abstract

A perfect comparison between a closed circuit of water current and a closed circuit of electric current is made and Ohm's law is obtained in this manner and it is shown that, contrary to the current belief, existence of conduction current is not because of the existence of any electric field in the conductor, and the linear relation $\mathbf{J} = g\mathbf{E}$ cannot be valid. The relaxation time (necessary for the current to reach its final speed) and the final speed (drift velocity) of the current are obtained in the above-mentioned manner, and it is shown that, contrary to what is believed at present, both of them are independent of the chosen standard unit charge (eg electron charge or coulomb) and its mass. It is also shown that, contrary to the current belief, alternating current is steady. We also prove the existence of a kind of resistance arising from the configuration of the circuit. Action mechanism of transistor is explained and a hydrodynamical analogue for it is introduced: both confirming the material presented earlier.

1 Introduction

What is presently propounded as the existence cause of an electric conduction current in a conductor is the existence of some electric field arising from the power supply (sources) in the conductor and the response of the conductor to this field in the form of producing current density (eg in the form of $\mathbf{J} = g\mathbf{E}$ for an ohmic material). In other words it is thought that existence of the conduction current necessitates existence of an electrostatic field producing it, and also existence of the potential difference necessitates existence of an electrostatic field causing it. And then an entire similarity is considered between the electrostatics and the subject of electric current, eg as in the electrostatics, the curl of the above mentioned field is considered equal to zero in the conductor and then eg it is tried that a conduction problem to be solved in the same way as an electrostatic problem (by obtaining appropriate solution to Laplace's equation (see Foundations of Electromagnetic Theory by Reitz, Milford and Christy, Addison-Wesley, 1979)).

In this paper considering the entire similarity existent between the electric current and mechanical current of water it is shown that, really, existence of the conduction current does not necessitate existence of any electrostatic field in the conductor (or wire) carrying the current, and the potential difference here is other than the potential difference in the electrostatics, and in this manner we obtain Ohm's law.

2 Water circuit and Ohm's law

Consider the water circuit shown in Fig. 1. This circuit is a closed tube full of water set on a horizontal level which its water is being forced to circulate by a pump in the tube.

Suppose that the pump is switched off and the water is motionless. We want to see what happens when the pump is switched on. By switching the pump on, its blades exert force on the water particles adjacent to them, and these particles transfer this force to other particles, and altogether the water gains speed gradually. In other words the energy transferred from the pump to the water immediately after switching the pump on causes increase in the kinetic energy of the water, ie the energy of the pump is conserved as increase in the kinetic energy of the water. But does the water in each cycle conserve the energy received from the pump as the increase in the kinetic energy of itself? If so, we must expect an infinite speed for the water after elapsing of enough time, while we know that this is not the case and after some time the speed of water reaches a constant limit while the pump is still in operation and is giving the water more and more energy. So, where does the energy of the pump, which no longer is conserved as increase in the kinetic energy of the water, go? The answer is that this energy is dissipated as heat in different parts of the circuit and the conservation law of energy remains consistent.

Let's see how every part of the circuit changes the energy of the pump into heat when the circulation speed of the water in the circuit has reached the constant limit. Imagine a definite drop of the water just when a blade of the pump is directly exerting force on it. This drop is propelled by this force (but since we have considered the situation of the constant speed of the water, this drop does not accelerate due to this force). When the drop has been pushed forward a little, the blades of the pump directly exert force on another equivalent drop which transfers this force directly to the previous pushed forward drop. In this same manner it is seen that the pump directly and indirectly exerts force on the first drop during its circulation in the circuit. Since, exerting this force on the drop, the drop is displaced, this force (being exerted by the pump) performs work on the drop. Therefore, the energy of the pump given to the drop is this same work performed on the drop which we show it by V and attribute it to some potential difference between two relevant points of the circuit (we mean by the "potential difference" the work performed on this (standard) definite drop by the above mentioned exerted force during the displacement between the two points). But we know that this work does not increase the kinetic energy of the drop. Thus, what occurs to this work which according to the conservation law of energy does not disappear? The answer is that this work appears in the form of heat arising from the friction, ie heat arising from the opposition of the drop to the drops in front of it which exerting opposite force (and consequently performing negative work) try to prevent the drop from accelerating.

Now let's see how much energy of the pump in every part of the circuit changes into the heat when the circulation speed of the water in the circuit has reached the constant limit. Suppose that a part of the circuit is as shown in Fig. 2 in which the arrow shows the direction of the water flow (or current). Suppose that the two lengths l_1 and l_2 are equal. We want to see what the magnitude of the above mentioned force (arising from the pump) exerted on the above mentioned standard drop will be in the part l_2 if this force is F in the part l_1. If only the tube shown by the dotted line, which its cross section is equal to A_2 and is positioning just opposite to the tube l_2, was to be displaced exerting force on the water of the tube l_2, the above mentioned force in the part l_2 would be still the same F. But the dotted tube is not the sole one displacing, and it is obvious that all the water of the tube l_1 will be displaced entering the tube l_2, because the two tubes l_1 and l_2 are in series and the water current, which we show it as I, is the same in each. The whole tube l_1 contains, in number, A_1/A_2 tubes each equivalent to the tube l_2, and the situation is similar to when this number of tubes are set in series and transferring their forces to each other finally exert their forces on the tube l_2 (see Fig. 3). It is obvious that in this state the above mentioned force exerted on the mentioned drop in the part l_2 is equal to $(A_1/A_2)F$. Since the ratio of this force to the force exerted on the drop in the part l_1 (ie F) is equal to A_1/A_2, we conclude that the force exerted on the standard drop is inversely proportional to the cross-section of the part of the tube in which the drop is located. Therefore also the work performed by the mentioned force exerted on the drop is inversely proportional to the cross-section of the part of the tube in which the drop is located, and since we know that this work is proportional to the length of the part of the tube having a constant cross-section which the drop must travel, altogether this work is proportional to l/A in which l is the length of the part of the circuit that has the constant cross-section A. In other words this part of the circuit dissipates as heat some energy of the pump which is proportional to l/A.

It was cleared that in series parts of the circuit everywhere the ratio l/A was more, some more energy of the pump would be dissipated as heat. Thus the ratio l/A is indication of the resistance to the water current in that part of the circuit, and we define it, when multiplied by a definite constant coefficient c, as "resistance" in a water circuit indicating it by R. Therefore, we showed if the current (I) was constant (which this occurred when the resistances were in series), then the potential difference between the two ends of a resistance (V) would be proportional to the resistance ($R = cl/A$).

Now consider some part of the circuit as shown in Fig. 4. The work performed on the drop by the above mentioned force when passing this part of the circuit, is independent of the choice of the path p, q or r, but the water current in these three paths is proportional to their cross-sections. As we can see the amount of prevention of p is more than of q, and of q is more than of r. Thus the criterion which we obtain in this state for the resistance is the same proportion of it to the inverse of the cross-section, and since l is the same for the parallel resistances in this state, the same definition of $R = cl/A$ is still true for resistance. Therefore, we showed if the potential difference (V) was constant (which this occurred when the resistances were in parallel), then the current in each resistance (I) would be inversely proportional to the resistance ($R = cl/A$).

Now suppose that the mass of our standard drop is m and suppose that the opposing force (of the other drops on the way in the circuit), which as we explained prevent the drop from accelerating, is proportional to the velocity of the drop with the proportion coefficient $-G$ (it is obvious that G is proportional to m, because the bigger the drop, the more the retarding force is). In this state supposing that the force exerting on the drop due to the pump is F and the speed of the drop is v we have the following equation of motion:

$$m\frac{dv}{dt} = F - Gv \tag{1}$$

When the speed of the drop (ie the speed of the water) has become constant, we have $dv/dt = 0$ and consequently $v = F/G$, ie v is proportional to F, and since in a constant resistance, v is proportional to I and F is proportional to V, we conclude that if the resistance (R) is constant then the current (I) will be proportional to the potential difference (V).

In summary, we showed, “If I is constant, then $R \propto V$, and if V is constant, then $R \propto 1/I$, and if R is constant, then $I \propto V$”. We conclude from these three deductions that $R \propto V/I$ which is the same famous relation of Ohm’s law in the ohmic electric circuits.

Here it is opportune to obtain the complete solution of Eq. (1). This will be $v(t) = (F/G)(1 - e^{-Gt/m})$ if the initial condition is $v_0 = 0$. Therefore, the relaxation time is $\tau = m/G$. Since as we said G is proportional to m, the relaxation time τ is independent of m. Likewise, since the above-mentioned force F exerted on the mass m (arising from the pump) is obviously proportional to the mass m, the final speed of the drop $v = F/G$, in which both F and G are proportional to m, is also independent of m. In other words both the relaxation time, ie the time that the water speed requires to reach its constant limit (see the beginning of this paper), and the final speed of the current, as it is expected, are independent of what the bigness or mass of our standard drop is.

As it is quite obvious there is a thorough similarity between the above water circuit and an electric closed circuit in which the one coulomb unit charge plays the role of the above mentioned standard drop, and in fact in electric circuits a quite similar event occurs, not as it is supposed at present an electrostatic field in the wires of the circuit arising from the battery causes flowing of the electric current in the electric circuit (eg see D. Halliday and R. Resnick, Physics, John Wiley & Sons, 1978)! The only role of the power supply, eg the battery, (similar to the role of the water pump) is putting into circulation the current of valence electrons of the wires using chemical reactions or electromagnetic effects or ..., and nothing else; not producing electrostatic field which necessitates existence of electric net charge assembly which really does not exist.

The fact is that it is thought erroneously that wherever there exist electric conduction current (I) and potential difference (V), they should have been produced because of the existence of some electrostatic field there, while this is not the case for the electric current flowed by a power supply, eg a battery, in a closed circuit, but, quite like in the above mentioned water circuit, this is only transferring of the force exerted on the electrons in the battery (or in other power supplies) which causes their motion throughout the closed circuit, not existence of any electrostatic field in the wires. Besides, the potential difference, by which we mean the amount of work performed on one coulomb of electric charge (or on a standard drop) when being transferred from one point to another point, is not produced necessarily because of an electrostatic field, but as we saw the above mentioned forces exerted by the battery and transferred through the train of electrons can produce it. (For better understanding of the above material, actuality of conduction has been presented in a simple manner in the 12th and 18th papers of this book.)

Attention to this point is also interesting that as we reasoned beforehand (when discussing the complete solution of Equation (1)), the relaxation time τ and the final speed v, both of the standard charge, are independent of the mass (and also of the charge) of the (standard) charge chosen as the unit charge (and then eg contrary to what is current (eg see Reitz, Milford, Christy, Foundation of Electromagnetic Theory, Addison-Wesley, 1979)do not depend on the mass or charge of the electron), and only depend on the kind of the conductor, because G depends on it.

Now let's see whether really the linear relation $\mathbf{J} = g\mathbf{E}$ is satisfied or not when the electrostatic field $\mathbf{E}$ is exerted in an ohmic conductor causing production of temporary current density $\mathbf{J}$ (which eventually leads to proper distribution of charge in this conductor such that the field will vanish inside it being normal to its surface on its surface). Consider a point inside the conductor in a time when the electrostatic field has not been exerted yet. The valence electrons are stationing themselves beside their atoms. Now consider the moment that an electrostatic field is exerted in this point. Certainly this is not the case that immediately after exertion of the field in this point, without elapsing any time, current density $\mathbf{J}$ becomes flowing in this point. It is quite obvious that a time interval is necessary for the valence electrons to separate from their atoms and becoming flowing produce the current density. Just at the beginning of this interval, while there exists the field $\mathbf{E}$ in this point, there is no current there (ie $\mathbf{J}$ is zero). After elapsing a fraction of the mentioned time interval, some current becomes flowing (ie $\mathbf{J}$ reaches a fraction of its maximum), and since this very amount of current accomplishes a fraction of the final distribution of charge (which will make the field vanish inside the conductor), the field $\mathbf{E}$ is also decreased becoming less than its maximum (approaching zero). This process continues until when the current reaches its maximum which is simultaneous with a more decreased field. After then both $\mathbf{E}$ and $\mathbf{J}$ will be decreased approaching zero. In summary we can see the process of the simultaneous changes of $\mathbf{E}$ and $\mathbf{J}$ schematically in Fig. 5. What can be deduced definitely is that $\mathbf{E}$ and $\mathbf{J}$ don't have any linear relation in the form of $\mathbf{J} = g\mathbf{E}$ with the constant coefficient g, even for the ohmic mediums.

3 Whether alternating current is not steady

We have the equation of continuity $\partial\rho/\partial t + \nabla \cdot \mathbf{J} = 0$. Steady current is a current in which, passing the time, concentration of charge in each point does not alter, or in other words the charge is not condensible or expansible, and then it is necessary that $\partial\rho/\partial t$ to be zero for steady currents which according to the equation of continuity it is also necessary that $\nabla \cdot \mathbf{J} = 0$ for these currents. But we should notice that in a steady current it is not necessary that the current has also a particular form, ie it is not necessary that $\partial\mathbf{J}/\partial t = \mathbf{0}$ for a steady current. Unfortunately this matter is not observed in many of the textbooks and circuits carrying steady currents are considered equivalent to direct current circuits with this wrong conception that alternating currents are not steady, while according to the above-mentioned point although in an alternating current circuit $\partial\mathbf{J}/\partial t$ is not $\mathbf{0}$, the alternating current is certainly steady, because in a closed circuit, including the power supply, carrying an alternating current, valence electrons of the circuit itself (not the external electrons added to the circuit) only alternately change direction of their circulation in the circuit, while, passing the time, the charge density is constant (and in fact equal to zero) in each point. The situation is quite like a closed tube full of water which its water is oscillating in the tube because of the alternating change in the direction of pumping the water by a pump installed in the tube as a part of it.

4 Resistance due to the configuration of the circuit

We intend to prove the existence of another kind of electrical resistance. This resistance is arising from the form of the current path. Current-carrying electrons are compelled to move within the boundaries of the current-carrying wire in order to cause the electric current. Thus, naturally, the form, or in other words, the configuration of the current path can cause a resistance on the path of the current that is other than Ohm's resistance, discussed above, arising from the nature of the current path (wire). The cause of this resistance is the mechanical stresses due to the collisions of the electrons with the materials of the current path and their pressures against these materials (the amount of which depends on the form of the current path). The situation is similar to the familiar case of a conductor having an excess electric charge: in this state the charge will be gathered on the external surface of the conductor and will exert an outward normal force (or an outward pressure) on the surface that (this force or pressure) will be canceled out by the mechanical stresses of the material of the (surface of the) conductor.

Attention to the following example will clarify the issue. Consider a part of a current-carrying wire (from a circuit) (Fig. 6(a)). (Suppose that the arrow shows the direction of the motion of the electrons.) Make a loop from this part as shown in Fig. 6(b) such that firstly the part ab of the path of "going" (related to the left (entrance) branch) of the loop and the part ab of the path of "backing" (related to the right (exit) branch) of the loop are very close together but without any contact (at present), and secondly these two parts of the "going" and "backing" paths (ie ab's) are quite parallel to each other. It is obvious that the current in the part ab of each of the "going" and "backing" paths is still from left to right having the same amount of the circuit current.

Now let's make these two parts (ab's) in (gentle) contact with each other. What is the situation of the current in this double part of ab now? If the (above-mentioned) resistance arising from the configuration of the wire did not exist, the most correct answer would be that we should not expect any alteration and as the path of the current would have become double in the distance between a and b (being both the "going" and "backing" paths) the current would be two times more than the general current of the circuit (because of the general current of the circuit both in the "going" and "backing" paths of ab). But certainly this is not the case completely, and due to the contact of the two "going" and "backing" parts of ab a part of the previously mentioned stresses will be redistributed (trying to become minimum) and then the above-mentioned resistance, arising from the configuration, will change and then the current in the loop and also in the common part of ab will be other than the case before the contact; the quite clear reason for this statement is that when the two parts of ab are in contact we expect in principle that because of the positioning of a before b the current in the loop to be counterclockwise (from a to b) not clockwise (from b to a) as before the contact.

Now imagine that these parts of ab are welded together, and in the distance between a and b we have only a single wire with a thickness equal to the wire thickness in other parts of the circuit (and loop). In this state if we want to visualize the situation just before the contact of the two "going" and "backing" parts of ab as one we explained above, we must say that before the above-mentioned gentle contact the cross-section of the circuit in the "going" part of ab and also in the "backing" part of ab is half of the cross-section in other parts of the circuit, then the speed of the electrons in each of the two "going" and "backing" parts of ab is twice as more as the electrons speed in other parts of the circuit. Now, if these two slenderized "going" and "backing" parts of ab are to be brought into contact with each other (welded together) and also if the currents are not to be changed, the situation will be as shown in Fig. 7, ie as we see in this figure, according to the above reasoning assuming ineffectiveness of the configuration on how the current is distributed, we expect that the current in the part ab of the circuit to be twice as more as the general current of the circuit half of which, of course, will be canceled as the "backing" (counterclockwise) current in the loop. It is obvious of course that this won't be the case in practice, because, as a rule, as we said, we expect in principle that because of the positioning of the point a before b in the current path the current in the loop to be (clockwise) from a to b.

The conclusion we can decisively draw is that, anyway, the inclination existent in the circuit to produce a counterclockwise current in the loop before the contact of the two previously separated parts of ab, now after the contact (or welding of the two parts), depending on the configuration of the current-carrying wire of the loop relative to the configuration of the main wire of the circuit, will have a noticeable effect on the current which as a rule is expected to be clockwise in the loop (because of the point a being before b); and, in practice, the current in the loop may be even counterclockwise, even with little current, depending on the case; ie in other words we can have a negative resistance (of the configuration kind) causing the current in the part between a and b to be more than the general current of the circuit. We have pointed to such a case in the 8th paper of this book. We can also try the experiment suggested in Fig. 8 in order to see whether the current in the loop is clockwise or counterclockwise, and with what current.

5 Action mechanism of transistor

As a general confirmation of the mechanism presented in this article for the resistance arising from the configuration of the current path and also of the validity of the comparison made between the electric current and water current we shall proceed to describe the action mechanism of transistor in this section.

We know that some different materials gather electrostatic charge when robbed with each other. Consider two typical materials of this kind and call them 1 and 2. Assume that some electrons will flow from 1 to 2 when they are brought into contact. Important for us in this discussion is the tendency (due to any reason, eg the molecular structure of the materials) existent in the contact between 1 and 2 to cause the electrons to flow from 1 to 2.

Now let's connect the negative pole of a battery to 1 and its positive pole to 2. The battery tends to make the electrons flow from its negative pole to its positive pole in a circuit external to the battery a part of which is the battery itself. Such a flow will be from 1 to 2 considering the above-mentioned connecting manner. But as we said, regardless of the stimulation of the battery, the materials 1 and 2 themselves have a tendency to establish an electron current from 1 to 2. Thus, it is obvious that the battery will establish a current of electrons, from 1 to 2, in the circuit without encountering much resistance (due to the junction 1-2).

But when the negative pole of the battery is connected to 2 and its positive pole is connected to 1, the battery as before wants to produce a current of electrons from its negative pole to its positive pole in the circuit a part of which is the battery itself, and this necessitates flow of electrons from 2 to 1 which is opposite to the natural tendency of the junction 1-2; thus, the electron current of the circuit will encounter much resistance at the junction 1-2. In other words for prevailing over this additional resistance in order to have a current with the same intensity as before in the circuit it is necessary to use a battery with a higher voltage.

Let's show the tendency of a junction to establish a current of electrons by an arrow in the direction of this tendency. Suppose that we have two adjacent junctions of the above-mentioned type (having natural tendency to make the electrons flow) but with two opposite directions of tendency in a single block; see Fig. 9. We name such a block as transistor.

Let's construct a circuit as shown in Fig. 10 using a transistor of the type (a) in Fig. 9, two batteries, some connecting wires and an on/off switch. When the switch is off we have only a weak clockwise current of electrons in the right loop. When the switch is on the clockwise electron current in the left loop begins and increases until the current has such an intensity that causes some part of the current previously flowed in the middle wire to be exerted on (ie to flow in) the right loop through the junction 2-3 causing increase in the weak current of electrons in this loop. And this will be more effective when the material 2 is thinner and wider because in such a case the electrons passing through the junction 1-2 will be exerted on (or will be forced onto) the junction 2-3 more readily and more effectively.

If we construct the circuit of Fig. 11 using a transistor of the type (b) in Fig. 9, we shall observe that while the switch being off there will be only a weak counterclockwise current of electrons in the right loop. And when the switch is on a counterclockwise current of electrons will begin and increase in the left loop. This current will become such intense that eventually a part of the electron current, previously flowed in the middle wire at the point c towards 2, now will be exerted on (or will go into) the right loop causing increase in the weak counterclockwise current of electrons in this loop. This will be more effective when the material 2 is thinner and wider because in such a case the electrons passing through the junction 3-2 will be exerted on (or will be forced onto) the junction 2-1 more readily and more effectively (causing increase in the electron current passing through the left battery which eventually will cause more increase in the electron current passing through the right battery).

Now imagine such an ideal state of the figures 10 and 11 (with switches being on) that the magnitudes of the upward and downward currents in the middle wire are the same and then these currents cancel each other. In such a state that there is no current in this wire (and a considerable current in the whole circuit) we can eliminate this wire from the whole circuit in principle. But, could we do this before switching on the switch? It seems that the answer is negative and the current in a circuit without the middle wire cannot increase to the extent accessible by a circuit with the middle wire (while the switch being on). If so, we have presented a practical (or experimental) confirmation of the starter mechanism (ie the first current in a loop that increases and eventually causes increase in the current in the other loop due to the exertion of the current pressure).

We can introduce for a transistor too a mechanical (or hydrodynamical) analogue which itself helps to understand the action mechanism of transistor better. Let's construct it as shown in Fig. 12. In this figure some hinged blades are set up one after the other in two adjacent surfaces A and B as their cross-section is shown in Fig. 12. Suppose that in one type of the above-mentioned hydrotransistor the blades of the surface A can be opened readily towards B and the blades of B can be opened readily towards A (Fig. 13(a)) while the blades of each surface can be opened towards the opposite side hardly (Fig. 13(b)), and in the other type the blades of each surface can be opened readily towards the side opposite to one in which the other surface is located while being able to be opened towards the other surface hardly (Fig. 14).

Let's construct the hydrocircuit of Fig. 15 using the hydrotransistor of the type shown in Fig. 13. When the valve is off and the pumps a and b are on we have only a slow clockwise water current in the right loop. But when the valve is on the clockwise water current will begin in the left loop and will be accelerated gradually and little by little the water will gain such (kinetic) energy that the blades of A will be opened completely and the accelerated and energetic water will force itself onto the blades of B too, causing them to be opened more and to let more water pass into the right loop and circulate clockwise. A hydrocircuit containing a hydrotransistor of the other type will have a function similar to what we explained previously about the electric transistor analogue with it.

Now suppose that the hydrocircuit shown in Fig. 15 have no middle tube. In such a case is it possible for the water to be accelerated gradually after switching the valve on until the same intensity of current is obtained that would be obtained if the middle tube existed? The answer is negative because when there is no middle tube the weak (or slow) clockwise water current produced in the circuit will soon reach an equilibrium state in which both the current intensity of the circuit and the amount of opening of the blades of B will remain constant on some small values. (The situation is quite similar to the right single loop of Fig. 15 itself in which there will be a small constant clockwise current in the loop corresponding to a small opening of the blades of B when the valve is switched off.) But the existence of the middle tube and the above mentioned mechanism cause the clockwise water current of the left loop to gain (kinetic) energy as much as possible and then to rush onto the blades of B opening them noticeably with its huge energy.

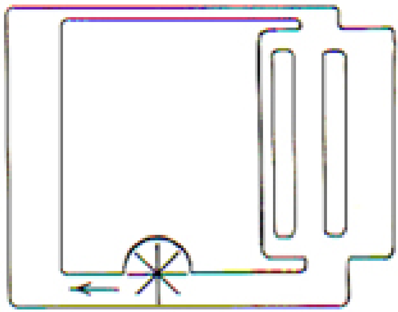

Fig. 1

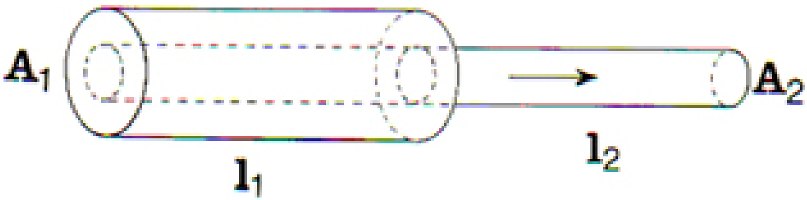

Fig. 2

Fig. 3

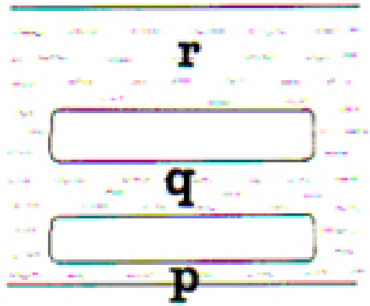

Fig. 4

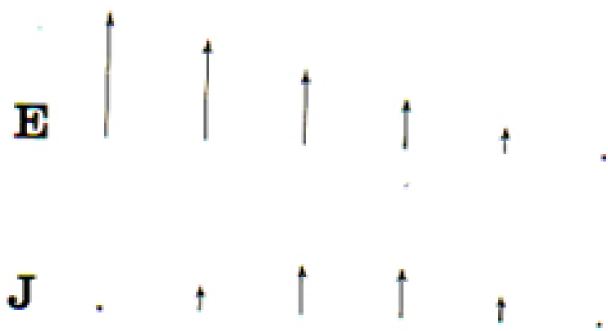

Fig. 5

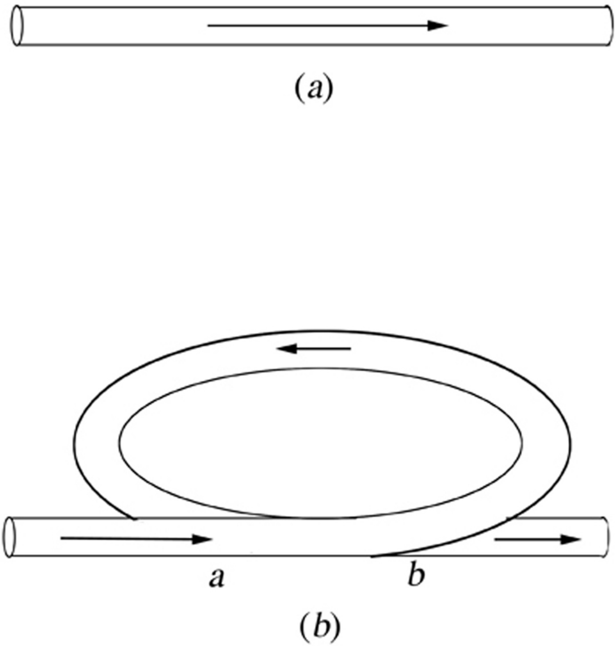

Fig. 6. *The current_carrying looped wire makes the electron move in the loop.*

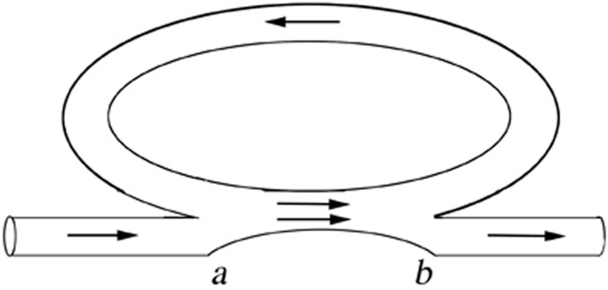

Fig. 7. *What is the situation of current in the part ab and in the loop?*

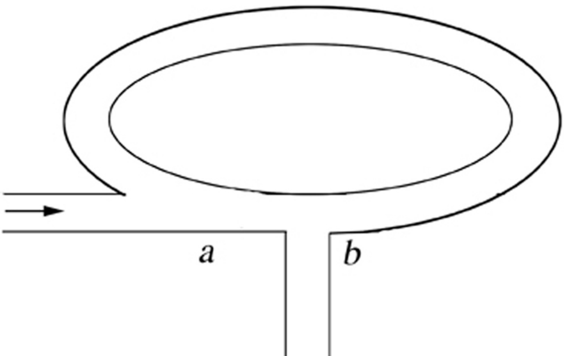

Fig. 8. *Is the current in the loop clockwise or counterclockwise?*

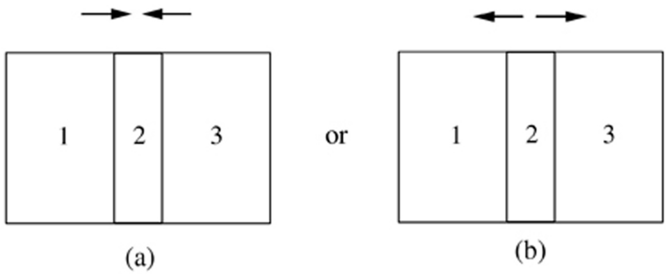

Fig. 9. *Two types of transistor.*

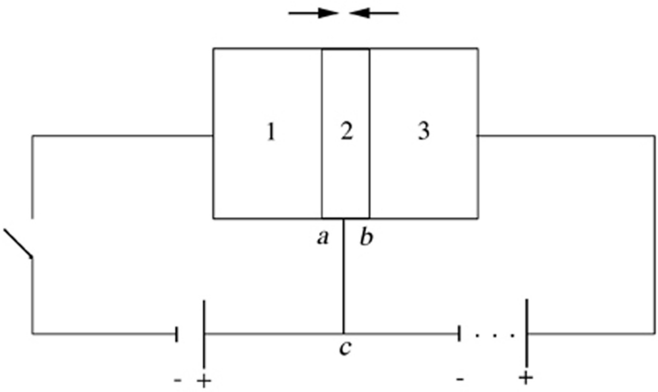

Fig. 10. *A typical circuit of a transistor of the type a in Fig. 9.*

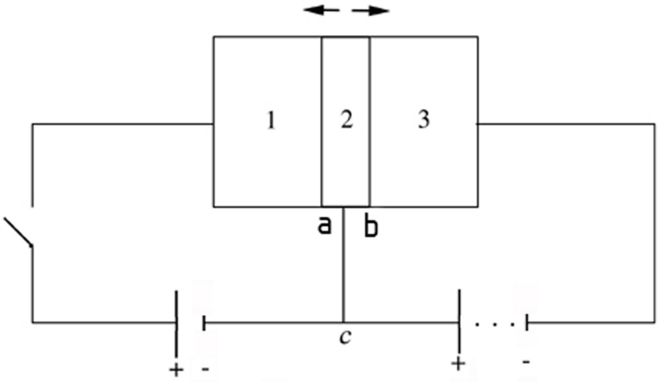

Fig. 11 . *A typical circuit of a transistor of the type* b *in Fig. 9.*

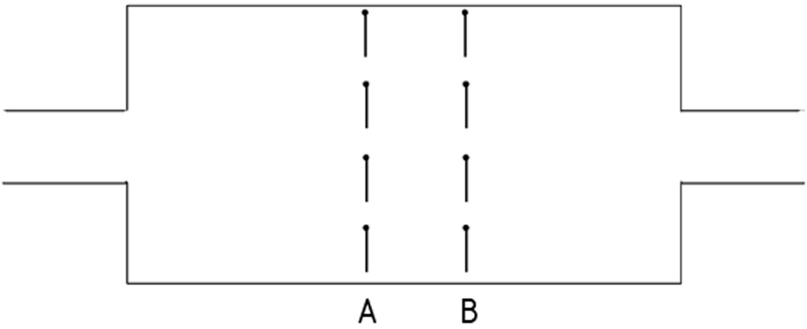

Fig. 12. *A hydrotransistor*

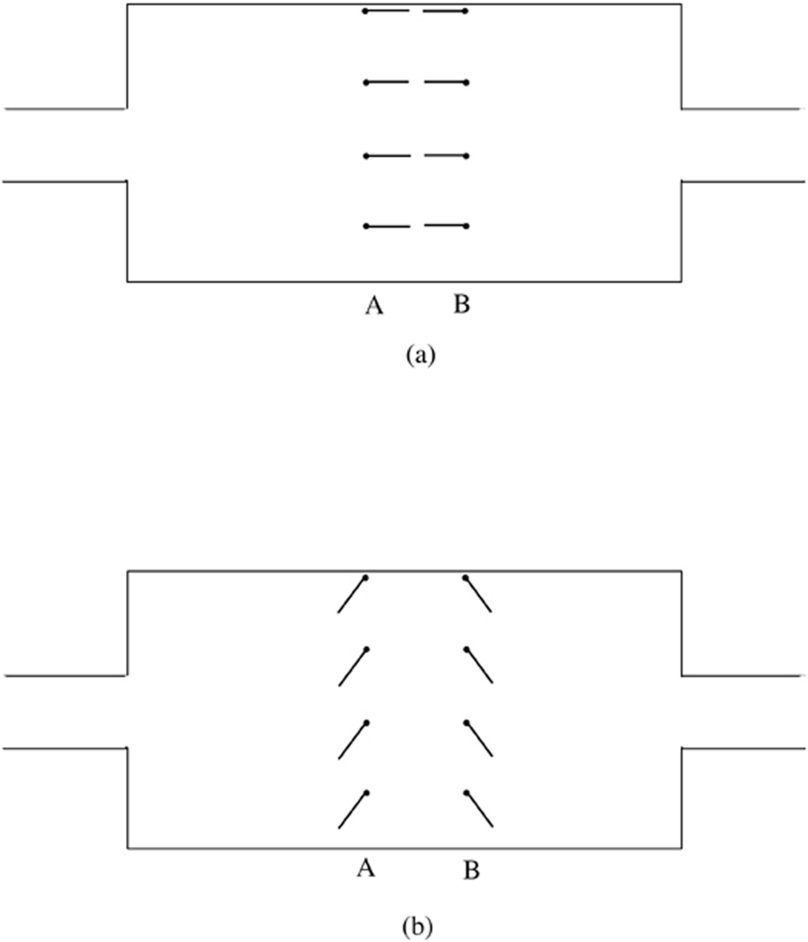

Fig. 13. *How a hydrotransistor of the type a works.*

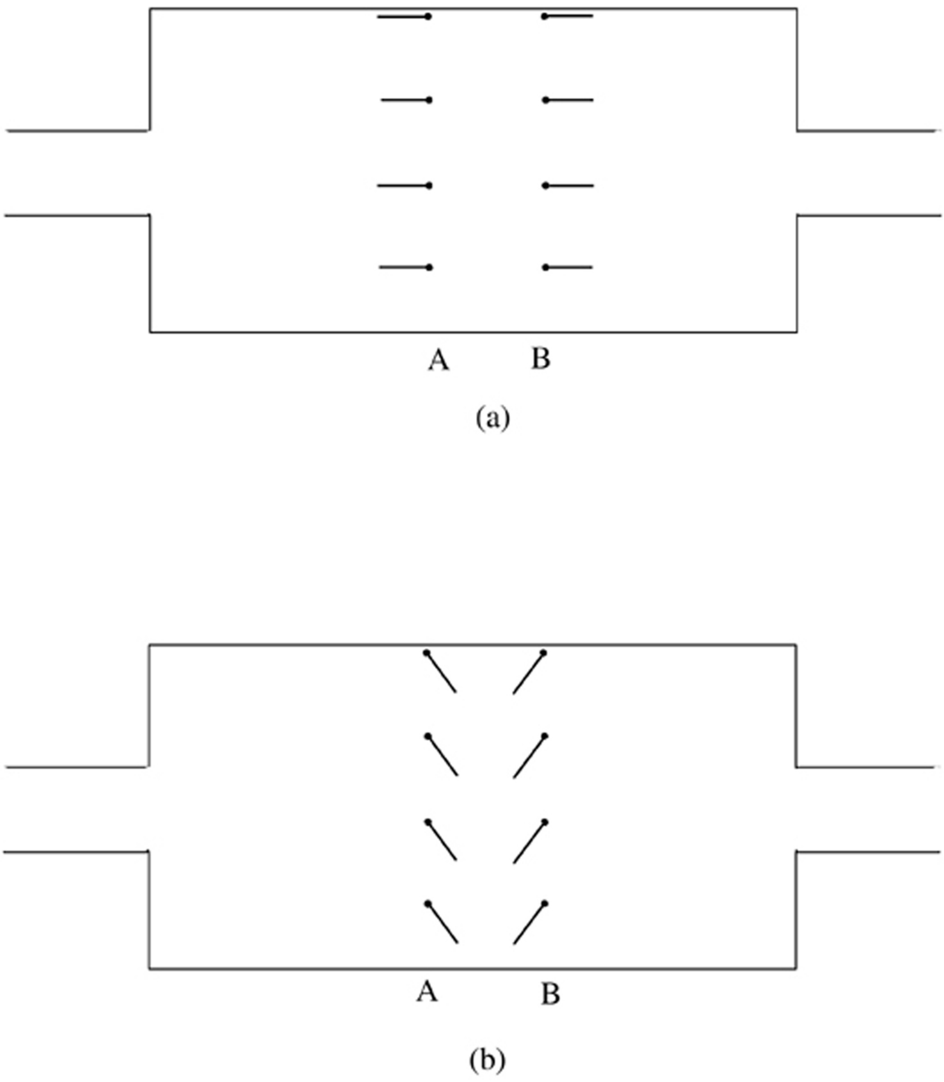

Fig. 14. *How a hydrotransistor of the other type works.*

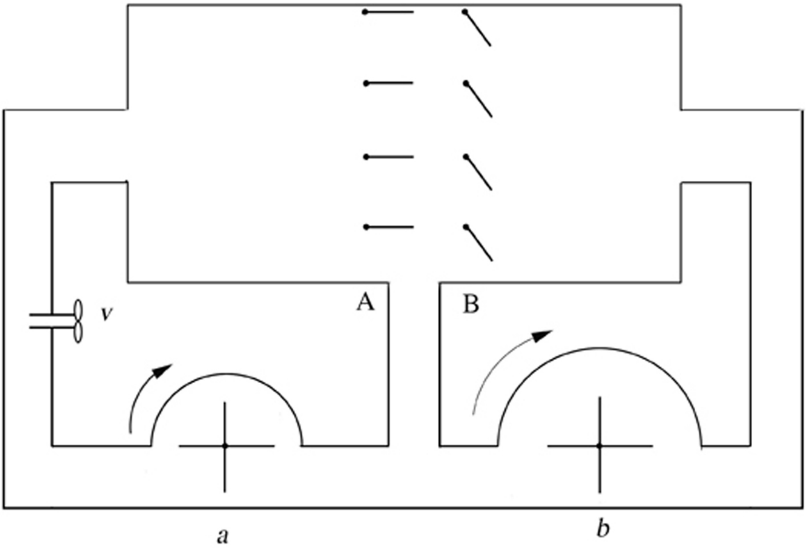

Fig. 15. *A hydrocircuit containing a hydrotransistor.*