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A case study about the comprehension of electromagnetic induction in Northern Italy

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Abstract We discuss a study about Italian upper secondary school, undergraduate and graduate students' and teacher's misunderstanding in dealing with electromagnetic induction. We suspect that most difficulties, that we found substantially common at all levels of education, come from the very poor link, generally presented in teaching, between the Faraday's law and the Lorentz force. We also suggest that the understanding of inductive phenomena/problems/exercises could benefit from taking into account also the magnetic vector potential "point of view".

Introduction

The recent reform (year 2010) of the Italian upper secondary school curriculum has given birth to two substantial anxiety generators in teachers: 1) some compulsory topics of modern physics and special relativity to be treated in the last (13th) grade; 2) the possibility of a written test on physics in the final national examination. To train teachers and students on this last point, some simulations prepared by the Italian Ministry have been put online [1]. Most of them contain non-trivial exercises about both modern physics and electromagnetism, in particular about Electro-Magnetic Induction (EMI). In response to teachers' needs, most of the Italian Physics Education Research (PER) groups have been called to deliver training courses for teachers about Modern Physics and Relativity for secondary school and – at least this is the Milan PER group situation – also to discuss EMI in deeper details than those generally given in textbooks.

Even if the Ørsted experiments are generally seen as the act of birth of Electromagnetism, the study of the static electric and magnetic fields can be considered not more than a great enrichment of the Classical Mechanics viewpoint. It is with EMI that one really enters the vast domain pertaining more specifically to Electromagnetic phenomena, the comprehension of which passes, therefore, through the gate of EMI. This consideration explains the efforts made by various PER groups on this topic in recent years (see [2-6] and references therein).

For a physicist, it is not difficult to recognize that EMI can be found everywhere, but, although it is relevant in everyday life – transformers, induction cookers and electric motors are ubiquitous – it is nonetheless far from everyday common experience. It could also be that at school EMI is not perceived in its full importance from both an educational and a practical knowledge point of view. Our idea, instead, is that EMI is the pivot, the watershed between a somewhat old-fashioned physics and a much more modern viewpoint where fields play a fundamental role; it is the concept a whole new physics started from. Moreover, EMI is interesting also because it is one of the (few) secondary school topics which, due to the abstractness of the content, cannot be "misunderstood" *via* the use of common sense schemes but only on the basis of what we may call "Disciplinary Common Beliefs" (DCB), that are disciplinary based, but not theoretically sound, interpretations of non-common phenomena or situations.

We therefore focused our interest on the comprehension of EMI at various educational levels. In this paper we analyse and discuss the answers to a written questionnaire taken from the literature (questions 29, 30 and 31 of the area X (Faraday's law) of the "Conceptual Survey of Electricity and Magnetism, see [4]; questions Q1 and Q3 from [5] and question Q4 from [3]).

Context and background

The Faraday's flux law (with obvious meaning of the symbols)

$$emf = -\frac{\mathrm{d}\phi(\boldsymbol{B})}{\mathrm{d}t}, \tag{1}$$

is often difficult to be understood even by professional physicists working at universities. For example, it is, in general, difficult to properly understand EMI in quite a number of different phenomena, namely: the Faraday disk, the homo-polar generator, the Blondel experiment and similar related devices. And, in fact, since the middle of 20° century, there have been many disciplinary discussions on the Faraday's flux law. Its general validity has been thoroughly debated from a disciplinary point of view, and only in the last two-three decades studies agree that there are no exceptions to the validity of Faraday's flux law. For a more detailed discussion, see [2, 3, 6] and references therein.

If experts are confused, it is not a surprise that even teachers and students show some uncertainties in dealing with EMI phenomena. In fact, PER has put in evidence many difficulties coming from the teaching and learning of EMI and there are now quite a few studies about the reasoning of students on EMI and their understanding of it; mostly (but not all) at university level [2-9]. The result is that "the vast majority of secondary school students and a significant part of first-year university students do not recognize EMI phenomena traditionally taught in the curriculum" [3].

Some of the most common students' difficulties can be roughly summarized as:
- Difficulties with the meaning of flux;
- Confusion between $\boldsymbol{B}$ and the time variation of $\boldsymbol{B}$;
- Confusion between $\boldsymbol{B}$ and the flux of $\boldsymbol{B}$;
- Misunderstanding about the area of integration in the flux rule;
- Difficulties in understanding the nature of the forces acting on the charges in motion;
- Confusion between the presence of an electric current and the presence of an EMI phenomenon.

Although the research results are clear, the somewhat peculiar situation of the Italian upper secondary school (the relatively "high" level of mathematics in the curriculum, that includes elementary calculus, and the supposed high disciplinary preparation of the teachers, that must have taken a master degree in physics or in mathematics) and the particular historical moment for what concerns the upgrading of the Italian curriculum deserve some attention.

For what concerns EMI, a document of the Italian Ministry addressed to the scientific high-school framework, identifies the knowledge, skills and competences which may be subject to verification in the final written examination. Here an excerpt:

"*Describe and interpret experiments that show the phenomenon of electromagnetic induction □ Discuss the physical meaning of the formal aspects of the equation of Faraday-Neumann-Lenz law □ Describe, even formally, the relationship between the Lorentz force and the induced electromotive force □ Use the Lenz's law to identify the direction of the induced current and to interpret the result in the light of energy conservation □ Calculate the variations of magnetic field flux □ Calculate currents and electromotive forces induced using the Faraday-Neumann-Lenz law also in differential form □ [...] □ Solve exercises and problems of application of the studied formulas including those that require the calculation of the forces on moving conductors in a magnetic field; □ Recognize the phenomenon of electromagnetic induction in experimental situations □ Examine a physical situation that involves the phenomenon of electromagnetic induction*"[10].

As a consequence, the final examination based on the national curriculum requires the skills/abilities/competences to solve complicated exercises and need also a robust qualitative framework; unfortunately, these requests seem somewhat away from the results given by the literature. Some issues thus quite naturally emerged: are we, in Italy, really in a better situation than the reported international one? Are Italian teachers prepared to teach EMI in depth?

Research design and method
Two research questions (RQs) were then formulated.

RQ1) Are the difficulties about the teaching/learning of EMI the same in Italy as those reported in the international literature?

RQ2) If and how, do these difficulties change at different levels of education, from secondary school students to students attending a master degree in physics, to physics teachers?

To get a first snapshot of the situation, our study has been carried out through the analysis of:

1) A 14 multiple choice questionnaire, taken from the literature [2-5], given to 16 students of the university course "Preparations of Didactical Experiences" attended by 4 students of the last year of the master degree in mathematics, by 9 students of the last year of the master degree in physics and by 3 graduated in physics;

2) A 6 hours course about EMI delivered to 7 high school teachers in the autumn 2017;

3) A 6 questions questionnaire – subset of the previous 14 questions questionnaire and translated into Italian – (see Appendix for the English version) given to students of the last year of a scientific high school that had already faced EMI at school. Explanatory answers have always been asked for every question. We have also conducted some oral interviews with 3 secondary school teachers, 5 graduate/undergraduate and 2 high school students.

In this paper we report only the analysis of the 6 common questions of the survey. We were principally interested in students' reasoning, and in order to answer correctly, students had to know that an electromotive force is produced by the flux of a time-varying magnetic field and by the circulation of the Lorentz force per unit charge, as given (with obvious symbology) by the formula:

$$emf = -\frac{\mathrm{d}\phi(\boldsymbol{B})}{\mathrm{d}t} = -\phi\left(\frac{\mathrm{d}\boldsymbol{B}}{\mathrm{d}t}\right) + C(\boldsymbol{v} \times \boldsymbol{B}). \tag{2}$$

For each question, the answers were grouped into categories according to the type of reasoning used, independently of the correctness of the answer. These categories were got from each question through a "negotiation phase" starting from the individual analysis made by every member of the research team, therefore the categories are not given *a priori* and, for each question, do not overlap. The answers that we were not able to categorize (mostly because we did not clearly understand the meaning of the written sentences) or those with no explanation have been put into the general set "Other". In the following, we give, for each question, a table with our categorization and some examples of the answers together with few comments. HSS means High School Students, 1MDM, first year of the Master Degree in Mathematics, 1MDP, first year of the Master Degree in Physics and PT means Physics Teachers.

Results

1.1. Question D1 (question 29 in Appendix)

Question D1 concerns the current that is possibly induced in a circuit when the magnetic field is variable or the loop is moving. Table 1 summarizes our categorization giving the number of answers per each category (one for each row) of each coherent students group (one for each column).

Table 1. Answers to D1				
D1	HSS (33)	1MDM (4)	1MDP (9)	PT (3)
FLUX	16	1	8	0
B	2	2	1	2
CONFUSION BETWEEN THE PRIMARY AND THE SELF-INDUCED B	1	0	0	0
OTHER	14	1	0	1

The "Flux" category groups, for this question as well as for questions D2 and D4, the answers in which the cause of EMI is principally ascribed to the variation of the magnetic flux. In the following, a few examples:

HSS: "*The magnet moves away creating a variation in the flux of the magnetic field that generates an induced current*".

HSS: "*The bulb lights up if there is an induced current, provided by a change of flux. In the first and second cases, either by moving the magnet away or by approaching the coil, there is a variation of the magnetic field and, consequently, also a flux variation which leads to the creation of an electric current. In the second case the radius of the loop decreases and therefore there is a variation of the surface*".

1MDM: "*I. The flux varies because the magnet moves away and then the magnetic field of the loop changes. II. The flux varies because the surface of the loop decreases and the field is fixed. It is similar to I, but it is the wire which is approaching*".

1MDP: "*I must have a flux variation through the loop. In I and IV I have it because the surface changes. In III I do not have it because neither the field nor the surface change.*"

In the answers to the questions D1, D2 and D4 in the "B" category we find those in which the cause of EMI is seen in the variation of the magnetic field.

Examples are:

HSS: "*The magnet, moving away from the loop, creates a variation of magnetic field that acts on the loop, since the field lines become weaker*".

HSS: "*The fact that the magnet is moving generates a variation of the magnetic field which causes an electric current to be generated*".

1MDM: "*The magnet that moves away or approaches changes the magnetic field inside the loop. Even the tightening wire changes the magnetic field inside the loop [...]*".

1MDP: "*They are the only ones in which there is a variation of quantities to induce a variation of the field B which induces a current that allows the object to shine*".

PT: "*In the cases reported, I have a variation of magnetic field concatenated to the loop. The induced current is a current that is generated in the loop to oppose the variation of the magnetic field*".

We also found one high school student that made "Confusion between the primary and the self-induced B". In fact he wrote that:

"*There is a variation of magnetic flux, which induces in the coil a magnetic field, which induces a current*".

As a comment, we see that nearly 90% of the first year master degree students in physics and 50% of the high school students reasoned in terms of flux variation, while no physics teacher did this way. Moreover, no one gave an answer in terms of the Lorentz force that, instead, is the cause of EMI in the cases II and IV of D1.

1.2. Question D2 (question 30 in Appendix)

Question D2 is about the current that is possibly induced in a circuit when it is nearby a very long current carrying wire; as above, table 2 summarizes our categorization giving the number of answers per each category (one for each row) of each coherent students group (one for each column).

Table 2. Answers to D2				
D2	HSS (33)	1MDM (4)	1MDF (9)	PT (3)
FLUX	10	1	6	1
B	3	2	1	0

ANGLE WIRE-MOTION	11	0	0	0
OTHER	9	1	2	2

Examples of the "Flux" category are:

HSS: "*The magnetic field lines generated by the current i in the wire clear away from the wire. Therefore, only in the case that the displacement has a component perpendicular to the wire, there will be a variation of the flux of the magnetic field and therefore an induced current*".

1MDM: "*The magnetic field generated by the wire depends on r. In order for a variation in the flow to occur in the (rigid) loop, the loop will have to move away or approach the wire, while maintaining a parallel motion there is no flux, no induced current*".

1MDP: "*There is induced current if there is a variation of flux through the surface of the loop. [...] Case I: the flux changes because the intensity of the field decreases. Case II: the same as in the case I. Case III: I have no change of flux because the loop is always at the same distance from the wire*".

PT: "*In the case of variable **B**, since div**B** = 0 the flux of the magnetic field lines through a closed surface must be zero, this is possible only if an induced **B** is generated*".

Three answers coming from the "B" category are:

HSS: "*Whether it moves in one direction or the other, what changes is the intensity of the field that acts on it*".

1MDM: "*c) Because, in the case I, the magnetic field is always perpendicular and therefore does not induce a current*".

1MDP: "*The magnetic field of an infinite wire is on circular lines of force. In all the 3 cases the velocity is orthogonal to the magnetic field so there is always an induced electric field, in all the cases*".

We also found that one third of the HSS (but no one of the others) think EMI is in some way related to the angle formed between the wire and the velocity of the loop (category "Angle wire-motion"). For instance:

HSS: "*In case I, the angle between the wire and the moving coil is 90°; the cosine is 0 and therefore the flux is null and there is no induction*".

HSS: "*The loop will be crossed by current only when the current and the velocity of the loop are not placed at 90° because the change of flux is nullified*".

1.3. Question D3 (question 31 in Appendix)
The presence of EMI in the absence of a closed loop is taken into account in question D3.

Table 3. Answers to D3				
D3	HSS (33)	1MDM (4)	1MDP (9)	PT (3)
FLUX	9	0	1	1
LORENTZ	4	1	2	0
NO SEPARATION	14	0	0	1
OTHER	6	3	6	1

Examples of answers from the "Flux" category are:

HSS: "*According to the right hand rule, the flux coming out of the plane, creates a current that moves counterclockwise*".

1MDP: "*There is no variation in the flux of the magnetic field (the surface of the bar hit by the field is always the same) so there is no induced current*".

PT: "*Answer (a) There is no variation in the flux of the magnetic field (the surface of the bar hit by the field is always the same) so there is no induced current*".

Here below, some answers coming from the "Lorentz" category:

HSS: "*By the right hand rule, the force created on the bar is directed downwards, so the distribution of the charges that is formed is that of the case (e)*".

1MDM: "*By the Lorentz force the charges are pushed downward*".

1MDP: "*A Lorentz force is acting on the charges of the bar. The positive charges then move downwards and the negative ones upward (towards the opposite side of the force)*".

In the "No separation" category we find (for examples):

HSS: "*The motion of the bar at velocity **v** in a constant and uniform magnetic field **B** does not change the charges of the neutral bar; therefore it remains the same as the initial figure*".

1.4 Question D4 (question Q4 in Appendix)

Question D4 concerns the current induced in a loop rotating in a uniform magnetic field and asks for the nature of the microscopic forces in action.

It is interesting to observe that the vast majority of students belongs to the "Flux" category and that only 1 (teacher) among the 49 students was able to explain that the force acting on the moving charges is the (local) Lorentz force (category "Micro").

Here the PT answer:

PT: "*The conduction electrons, free to move inside the conductor, move with velocity v = v(therm) + v(cond) where v(therm) is the velocity due to the thermal agitation and v(cond) the velocity of their part of the conductor at a given moment. v(therm) is distributed in all directions while the speed of the rotating conductor is not. Therefore the electrons are affected by a Lorentz force [...]*".

Table 4. Answers to D4				
D4	HSS (33)	1MDM (4)	1MDF (9)	PT (3)
FLUX	25	1	6	0
B	0	1	1	2
MICRO	0	0	0	1
OTHER	8	2	2	0

1.5. Question D5 (question Q1 in Appendix)

Question D5 is about a U-shaped conductive wire that slides along a magnet which is also conductive. In this question the importance of equation (2) is particularly evident. In fact, an electromotive force is generated in the wire by the Lorentz force term. On the contrary, nearly all the answers, whether coming from the high school students, from the master degree students or from the physics teachers, are biased by the DCB that, since when the loop is stationary there is no flux because the magnetic field lines are parallel to the loop, there is still no flux (variation) when the loop is moving.

Table 5. Answers to D5				
D5	HSS (33)	1MDM (4)	1MDP (9)	PT (3)
NO CURRENT BECAUSE NO FLUX	29	0	3	2
LORENTZ	0	0	2	0
OTHER	4	4	4	1

Examples are given below.

"No current because no flux" category:

HSS: "*The magnetic field lines form an angle of 90° with the normal to the surface identified by the wire and part of the magnet. This means that the flux is zero and persists in its value as the wire slides downwards. There will therefore be no induced current*".

1MDP: "*There is no induced current because there is no variation of the flux of **B** (the angle is always the same)*".

PT: "*No, the lines concatenated to the loop do not vary*".

It is particularly interesting to observe that one HSS with no previous knowledge of flux cutting, spontaneously described/noticed a variation of the area:

HSS: "*The area changes because the wire moves up and down*".

"Lorentz" category:

1MDP: "*The downward movement of the wire implies the vertical movement of the charges inside it and therefore a current*".

1.6. Question D6 (question Q3 in Appendix)

Question D6 concerns the presence or absence of EMI when in a uniform and time-independent magnetic field a switch closes a circuit and opens a wider one. The DCB naïve reasoning that there is a flux variation because the area of the circuit changes dominates the answers and spans all the groups of students.

We also found 6 HSS reasoning in terms of a not well specified self-inductance of the circuit. It seems to us quite remarkable that, instead, only two HSS were able to give a somewhat correct answer.

Table 6. Answers to D6				
D6	HSS (33)	1MDM (4)	1MDP (9)	PT (3)
FLUX/AREA	7	1	5	1
OPEN CIRCUIT	5	0	1	0
B CHANGES SINCE THE AREA CHANGES	0	1	0	0
SELF-INDUCTANCE	6	0	0	0
"CORRECT"	2	0	0	0
OTHER	13	2	3	2

Here below a few examples:

"Flux/Area" category.

HSS: "*An induced current circles because, passing from position A to position B, there is an increase in the area of the circuit immersed in the magnetic field. Varying the area also the flux varies*".

1MDP: "*Yes, moving from position A to position B the circuit increases its area. Since field **B** is uniform, the flux increases instantaneously and there is an induced current spike*".

"Open circuit" category.

HSS. "*The fact that the switch disconnects from A and closes the circuit in B does not allow the formation of an induced current because in the intermediate passage the circuit remains open*".

1MDP: "*While the switch goes from A to B the wire is interrupted so a current cannot pass*".

"Self-inductance" category.

HSS: "*For a short time, we will observe the passage of current which will lead to the variation of the magnetic flux and to the creation of emf and then of an induced current in the opposite direction*".

"Correct" category.

HSS: "*There is no current induced. Because by moving the switch from A to B, I do nothing that can create a current, I do not change the characteristics of the circuit*".

HSS: "*No induced current passes, because no change in the flux occurs. The flux variation is due to the area [...] or to the field [...] or to the angle between **B** and the normal. In this case, none of the three things happens*".

Comments and conclusions

For what concerns RQ1), the majority of our results are in agreement with those found in the literature [2-9]. In particular, the majority of students tend to use the Faraday's flux law even when a description in terms of the Lorentz force could be very useful and easier. Except for the "standard" textbook cases (see the answers to D4), when using the flux law, students are in general unable to consider the right surface for the variation of the magnetic flux, both in presence of a motion of the circuit and in its absence. Most students are unable to describe the induced current in terms of forces acting on charge carriers (again see the answers to D4).

Concerning RQ2), we observe that, while some basic concepts have been gradually better understood with growing the level of education, for others the level of understanding remains substantially unchanged. An example of the first situation regards the concepts of circulation and flux: in the answers given to our questions, we see that most of our secondary school students have difficulties about their meaning, but no graduate in physics shows misunderstanding about them (at least in the simplest cases).

The two most interesting examples of the second situation regards: a) the greatly preferred use of the Faraday's law with respect to the Lorentz force in dealing with EMI (in general, confusing the circuit surface with the integration area) that does not change with the level of education, and b) the ability to connect a systemic description (electromotive force) to locally acting forces, that improves very little from secondary school students to physics teachers.

From a didactical point of view, we believe that some more attention should be deserved to this last point, since a deeper comprehension of the local acting forces may lead to a better understanding of the physical roots of EMI. In fact, while it is surely the Lorentz force that is acting on a conducting wire moving in a magnetic field, on the contrary, it is not the Lorentz force which acts on the wire when the wire stays still and the source of the non-uniform magnetic field is moving. This fact may be very confusing (consider, for example, we were interested in the forces acting in the situations described in D1).

The asymmetry found between the physical explanation of the two situations (conductor in motion – sources of **B** fixed, conductor fixed – sources of **B** in motion) is well known, but it has its full resolution only in special relativity. Nonetheless, especially for students that do not know relativity, if we do not linger upon this asymmetry problem, the common explanation of the forces acting locally on the wire is that it is precisely the variable magnetic field that generates a non-conservative electric field that acts on the conductor.

In our opinion, at least from a pedagogical viewpoint, this kind of explanation is not well grounded. In fact, there is no fundamental equation that gives the electric field in terms of the time variation of the magnetic field. The Maxwell equation $\nabla \times \boldsymbol{E} = -\partial\boldsymbol{B}/\partial t$, which one often refers to, gives a sort of topological (it gives the curl of $\boldsymbol{E}$) local property of the electric field – and means only that, if there is a time-dependent magnetic field, there is also, simultaneously, a non Coulombian electric field – but does not give $\boldsymbol{E}$ explicitly. At best of our knowledge, there are only two equations that, on the contrary, explicitly give the electric field acting on a conductor immersed in a time dependent magnetic field. One is the Jefimenko's equation for the electric field [11] that relates the electric field not to the time dependent $\boldsymbol{B}$, but to the time-varying charge and current density (that can be therefore

seen as the sources of the electric field). The other equation is $E = -\frac{\partial A}{\partial t}$ that gives E in terms of the time variation of the magnetic vector potential A. Both equations are to be used to understand the physics of the problem, but, while the Jefimenko's equation is surely beyond high school students' knowledge, the vector potential can, in our opinion (see [12]) be usefully introduced at high school level.

The difficulties we found in students' understanding of EMI, persistent at all educational levels, indicate that the traditional, somewhat standard introduction of EMI via the Faraday's law, evidently presents some educational bugs. From our results, it also follows that a way to better understand EMI should pass through a more strong connection between the flux law and the Lorentz force. But also a new suggestion comes out: on the basis of a preliminary pilot study [13], we hypothesize that the use of the magnetic vector potential already at high school level [12] may cure some of the diseases generated by the standard introduction of EMI and, besides other advantages (i.e. help the understanding of circulation and flux), gives rise to a path for the teaching of induction that is complementary to the traditional one and might also be more effective from a didactical point of view.

In most common presentations, but also in papers discussing EMI from an educational point of view, it is difficult (if not impossible) to find any definition of induction; this fact seems quite a bit surprising since in many questionnaires coming from the literature, and delivered to students to test their comprehension, questions like "would the magnetic induction occur?" are frequent. To fill this gap, we do propose to explicitly give a (unifying) definition of induction: "*Induction is the separation/movement of charges in a conductor due to the presence of an electric field*".

Since the general expression of an electric field (see Maxwell's Treatise, Art. 619) is given by

$$E = E_c - \frac{\partial A}{\partial t} + v \times B, \tag{3}$$

where we have indicated with E_c a Coulombian electric field, it is quite natural to say that, if at RHS of equation (3) the only term different from zero is the first, we have *electrostatic induction*; if, on the contrary, only the last two terms are not null, we say that we have an induced electric field and that, in presence of a conductor, *EMI* occurs.

We underline that, in this way, EMI is not defined via the flux rule, but through the local equation (3) making an explicit use of the magnetic vector potential. An experimentation based on this suggestion is under construction and hopefully will be the argument of a following work.

Appendix

The five separate figures below involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. These figures are to be used in the following question. The plane of the wire loop is perpendicular to the reference axis. The states of motion of the magnet and of the loop of wire are indicated in the diagram. Speed will be represented by v and CCW represents counter clockwise.
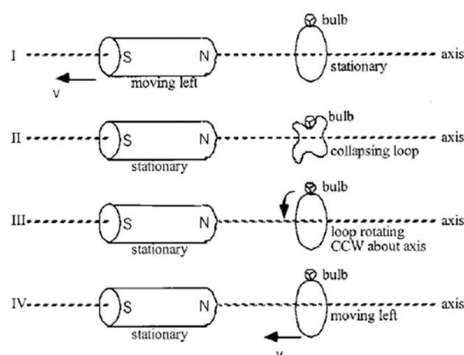
29.   In which of the above figures will the light bulb be glowing?

(a) I, III, IV   (b) I, IV   (c) I, II, IV   (d) IV   (e) None of these

30. A very long straight wire carries a large steady current i. Rectangular metal loops, in the same   plane as the wire, move with velocity v in the directions shown. Which loop will have an   induced current?
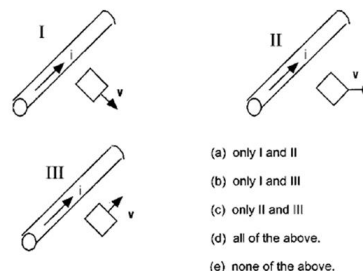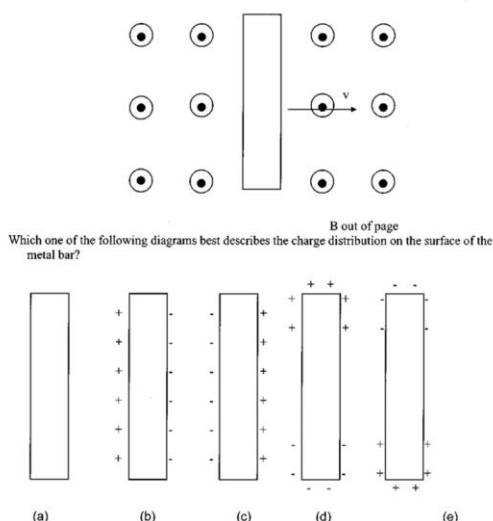

(a) only I and II

(b) only I and III

(c) only II and III

(d) all of the above.

(e) none of the above.

Q4. When changing the direction of the loop, it is found experimentally that the ammeter G in the loop registers a current. Explain where the forces which move the charges in the loop come from and the nature thereof.
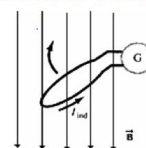
31. A neutral metal bar is moving at constant velocity v to the right through a region where there is a uniform magnetic field pointing out of the page. The magnetic field is produced by some large coils which are not shown on the diagram.

B out of page

Which one of the following diagrams best describes the charge distribution on the surface of the metal bar?

(a) (b) (c) (d) (e)

Q1. A U-shaped wire is sliding along a magnet as shown in the figure, maintaining its angle to the magnetic field. Bearing in mind that both the wire and the magnet are conductors, does an induction phenomenon occur in the wire? Justify your answer.

Q3. In the diagram, we can see a circuit with a switch immersed in a stationary magnetic field. This switch passes from position A to position B. Will there be induced current in the circuit? Explain your answer in detail.
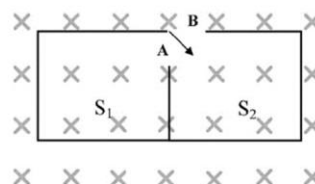
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