The Gauss and Ampere laws: different laws but similar difficulties for student learning

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Abstract
This study aims to analyse university students' reasoning regarding two laws of electromagnetism: Gauss's law and Ampere's law. It has been supposed that the problems seen in understanding and applying both laws do not spring from students' misconceptions. Students habitually use reasoning known in the literature as 'common sense' methodology that leads to incorrect forms of reasoning. To test our hypothesis, questionnaires were designed emphasizing explanations. The results obtained show the low level of students' reasoning in both electricity and magnetism in terms of Gauss's and Ampere's laws.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

University professors share the belief that the concepts used in the area of electromagnetism are a source of confusion for students [1–3]. Moreover, the graphic representation of the field using lines of force misleads students, who tend to display them as 'force tubes' giving them a 'real' quality instead of considering them as graphic models devised by scientists to explain electromagnetic interaction [4].

In this study we are going to analyse students' reasoning in the field of electromagnetism and, more precisely, when applying Gauss's and Ampere's laws, within a Maxwellian theoretical frame, using integral formulae in a vacuum. In our study, we shall stick to stationary electrical and magnetic fields, that is, those constant in time within the classic theory of electromagnetism, defined by Maxwell's laws. Our aim is to answer the following questions.

- Which forms of reasoning do students use when applying Gauss's and Ampere's laws?
- To what extent can the mistakes made by students in applying Gauss's and Ampere's laws be explained by means of spontaneous or 'common sense' forms of reasoning?

The relevance of Gauss's and Ampere's laws is not only justified by the fact that they provide a much easier way to calculate fields, in some specific symmetry situations, than Coulomb's and Biot–Savart's laws, but also by the fact that they respond to an electromagnetic interaction field model. In this interpretation we take into account the concept of field, instead of the concept of action-at-a-distance used in the Newtonian theory. Within the concept of field, it is still admitted that interaction exists in the moving charges, but such existence is supposed to go beyond the limits of the charges, and this interaction does not happen instantaneously. This conception includes retardation and this is the reason why Ampere's law is relativistically correct, whereas the Biot–Savart law is not. Ampere's and Gauss's laws belong to the set of basic equations for electromagnetism; these equations represent a 'field model' developed by the scientific community in order to explain electromagnetic interactions in Nature. Thus, clear comprehension of the features emphasized for Gauss's and Ampere's laws is crucial for students to be able to apply them correctly and achieve learning based on the theoretical and scientific framework [12].

As a result of the lack of knowledge on students' learning difficulties in this area, instructors face a more difficult situation than in other areas when we come to designing teaching sequences and strategies. We think that the study presented here can contribute to clarifying teaching strategies that will allow students to attain clear comprehension of the aforementioned laws.

2. Functional fixedness and reduction as spontaneous forms of reasoning to be considered in physics education

Spontaneous reasoning and reasoning induced by instruction itself can result from 'common sense' methodology [6] and from the difficulties detected by cognitive psychology when studying the methods used by problem solvers. In this study, we shall deal with two types of reasoning: fixedness [7] and functional reductions [8].

One of the characteristics of 'common sense' methodology is trying to find fast solutions to complex problems. This form of reasoning usually employs a single strategy which generally involves specific and direct application of a 'recipe'. The problem solver is only concerned with immediate consistency between the theory and the result obtained; as such they do not think about global consistency with other results and with the theoretical framework. In contrast, scientific reasoning is usually richer and more rigorous. In general, scientific work justifies adopting strategies and forms of reasoning which lead to obtaining results.

However, we frequently find teaching procedures in physics which involuntarily encourage repetitive learning of a strategy which, frequently, has no meaning for the student. Furthermore, if different teachers reiterate the same algorithm as if we were, for example, teaching to divide and multiply off by heart, *functional fixedness* of this procedure can occur. Even though the procedure enables the student to reach the final conclusion, it may prevent him from imagining other strategies and, therefore, it hinders creative or productive thinking [9].

At times other forms of reasoning are used, for instance spontaneous or induced reasoning, which is called *functional reduction* by educational research. Viennot [6] defines this concept as the tendency to reason in such a way that one does not consider all the variables which influence a problem. The most common instance of this type of functional reduction is the reduction of the number of variables in a multivariable problem, which leads students to 'forget' some of the fundamental variables. For instance, abundant literature on difficulties concerning simple electric circuits explains that students only take into account two variables out of the many involved in the circuit [10]. With respect to this type of reasoning,

Andersson [7] finds that it is as if an effect can be the result of multiple causes which were reduced to simple causalism along the lines of 'one effect is produced by one single cause'.

Yet another form of reasoning considered as functional reduction is what Rozier [11] called *linear causal reasoning*, which usually occurs in multiple variable situations that demand complex arguments and where the solver gradually diminishes the complexity of the problem by constructing simple implications in the style '*one cause one effect*' in the form of a linear chain, without ramifications in the argumentation, a chain that progresses sequentially until it reaches the final solution.

3. The study

In view of the need to establish a close relation between learning theoretical concepts and scientific reasoning skills so that students learn the theoretical corpus, we shall need to take into account not only their previous ideas, but also the way they use them in their reasoning. From this point of view, we designed a questionnaire where the questions placed an emphasis on the students' explanations. We have designed one paper-and-pencil questionnaire and an interview based on the previous bibliography review and our experience as teachers. The questionnaire has seven questions similar to those in the textbooks used for teaching Introductory Physics in university. The first three questions were about Gauss's law, while the following four questions were about Ampere's law (see the appendix).

To devise the current questionnaire, a prior study was carried out to analyse the coherence between the way the questions were written and how the students answered [12]. These studies confirmed that, in general, students had no problem in understanding the meaning of the questions but they show serious difficulties in applying Gauss's and Ampere's law correctly.

The interviews were based on four questionnaire tasks (questions 1, 3, 4 and 7) in an attempt to get an in-depth look at how the students apply Gauss's and Ampere's laws in three situations. Similarly, the interviews also tried to see whether there was any convergence between these explanations and those given by the students in the questionnaire. The interviews lasted approximately 40 min and were designed so that, firstly, the students would first propose the strategy to be used in Gauss's or Ampere's law and then justify that strategy. Secondly, they were to apply the law to the question, and thirdly stimulation was provided for students to perform critical analysis on the result and, where applicable, rework the question [13].

Sixty-five students from two first-year engineering classes filled out the questionnaire. The two classes were chosen randomly from the six first-year engineering classes at the University of the Basque Country (Spain). The students completed the questionnaire under examination conditions during a class lasting 55 min. Another 18 students from these classes voluntarily took part in the interviews. Competent, experienced physics teachers had instructed all the groups. Students received four lectures per week and laboratory sessions were held 1 h a week.

4. Results and discussion

In order to make it easier to present the results which were obtained, we shall display them in two sections and also include qualitative results from the interviews.

- How do the students use field sources when they apply Gauss's and Ampere's laws?

Table 1. Percentage of answers by students to questions 2, 4 and 5.

Answer category	Question 2 percentage of answers	Question 4 percentage of answers	Question 5 percentage of answers
A: all the charges or currents in the universe produce the field	7	9	9
B: only the charges/currents inside the Gaussian/Amperian pathway produce the field	57	60	66
C: the answer is not justified	9	11	13
D: impossible to categorize	27	20	12

Questions 2, 4 and 5 were designed with the intention of investigating the reasoning used by students in a situation where it is explicitly necessary to take into account which field is involved in Gauss's law (question 2) or Ampere's law (questions 4 and 5).

The answers given by the students have been categorized as shown in table 1.

In category A, we have grouped the correct answers which indicate that the electric or magnetic field calculated by Gauss's law or Ampere's law is due to all charges/currents in the universe (all plane charges in Q2, all current loops in Q4, the three currents in Q5). Examples of answers included in category A are as follows.

- Example 1 (Q2)
  'The field that is applied in Gauss's law is formed by the charges inside and outside the Gaussian, although in the formula it is the one inside the Gaussian.'
- Example 2 (Q5)
  'The answer is not correct, because acting on any point of the line is the magnetic field produced by the current from within and the magnetic field generated by the other current cable. I believe that... we have two magnetic fields to put inside the integral. I do not believe that it is easy to do this kind of exercise. I believe that the integral is complex.'

However, in Q2, no answer includes a justification, such as only the presence of all the charges allows for the existence of a special symmetry for the electric field, which in turn allows the type of simple mathematical treatment which we are familiar with for Gauss's law. In the same way, in Q4 and Q5 students do not justify why it is necessary to take into account all currents-loop (in Q4) or two currents (in Q5).

In category B, the vast majority of the students' reasoning is based on the formula. Students establish a causal link between the charge (Q2) or current intensity (Q4, Q5) enclosed by any closed surface/path and the field at the points on that surface/path. They wrongly infer that the only sources of the field are those enclosed by the Gaussian surface or Amperian path. We can observe this form of reasoning in the following examples.

- Example 6 (Q2)
  'If we apply the equation from Gauss's law, we see that $E = q_{in}/\varepsilon_0 S$ and therefore it is the internal charge that creates the field.'
- Example 7 (Q4)
  'According to Ampere's law, I applied the field circulation for that line, and as we have already seen in class. In the vertical segment and in the external part there is no circulation of B. Therefore, you would get field B from there, because we know the intensity that circulates through the loops: $\mu_0 \Sigma I_{internal} = \oint \vec{B} \cdot d\vec{l} = B \oint dl = Bd$.'
- Example 9 (Q5)
  'I agree, because $\oint \vec{B} \cdot d\vec{l} = B2\pi R = \mu_0 I_1 \Rightarrow B = \frac{\mu_0 I_1}{2\pi R}$.'

According to the students' reasoning, it seems that there is fixedness [14] with respect to a solving strategy based on the mathematical expression of Gauss's law or Ampere's law. It seems that, by using the formula, they establish a causality link between the charge or current enclosed by any surface and the field at the points on that surface.

In question 2, within category B, there is another type of 'ad hoc' reasoning, which would be associated, according to the bibliography, with a 'common sense methodology' that is frequently characterized by an absence of doubt, by sure, fast answers based on 'common sense evidence' and a lack of consistency when analysing the situation [3, 13]. One example is as follows.

In questions 4 and 5, some answers, although to a lesser extent, show forms of reasoning which confuse the field with the field circulation operator. See the following example.

- Example 12 (Q5)
  'It is true because the Amperian line does not enclose any current and the equation $(\oint \vec{B} \cdot d\vec{l} = \mu_0 \Sigma I)$ tells us that we only have take into account enclosed intensities.'

The interviews run on question 4 allow us to carry out a more in-depth analysis of the processes used by the students when applying Ampere's law to this problem. Let us look at an example from category B, which is common to 14 of the 18 students interviewed.

(1) Interviewer: How do you apply Ampere's law to this case? (Q4)
Student: Well, it was easy, because the problem gives me the integration curve. I apply the field circulation for that line, and as we have already seen in class, on the vertical sides and in the external part there is no circulation of B. Therefore, you would get field B from there, because we know the intensity that circulates through the turns:

$$\mu_0 \Sigma I_{\text{internal}} = \oint \vec{B} \cdot d\vec{l} = B \oint dl = Bd.$$

'd' is the length of the rectangle of integration.

(2) Interviewer: Is the field B that you calculated what creates the whole solenoid or only the turns that are inside the integration curve?
Student: The formula is for the turns inside the integration curve, so these are the ones that create field B.

(3) Interviewer: But if you take a larger integration curve, for instance we take 15 turns, would the magnetic field obtained change?
Student: Well (he hesitates). I don't know. I would have to calculate (further hesitation)... I don't think so, because it would increase the intensity of the current, but also the length d of the curve of integration... I think it would remain the same... I believe I am right, because in class we have seen that the formula of B works for the whole solenoid.

(4) Interviewer: So the B calculated is what is generated by the internal turns or those from the whole solenoid?
Student: What a question. I hadn't thought of that... (he thinks)... I think that B is only what is created by the internal intensity. That is what it says in the formula. But, I think that once it is calculated, it is good for the whole solenoid, because the intensity circulating through the cable is the same.

In the interview, it has been shown that most of the interviewed students have fixedness upon the formula from Ampere's law ('I think that B is only what is created by the internal intensity. That is what it says in the formula'; section 4). It seems that students do not understand the physical meaning of the law. Likewise, it has been possible to verify that they calculate B (section 1) without specifying the directions of the field vector and the dl vector

Table 2. Percentage of answers to questions 1, 3, 6 and 7.

Answer category	Question 1 percentage of answers ($N = 65$)	Question 6 percentage of answers ($N = 65$)	Question 3 percentage of answers ($N = 65$)	Question 7 percentage of answers ($N = 65$)
A: correct answer	19	18	15	9
B: confusion between the flux/ circulation operator and field	56	57	58	66
C: impossible to categorize	18	13	13	13
D: no answer	7	12	14	12

of the curve. It seems as if the student does not take into account the pattern of field and he considers that *B* and *dl* vectors are always parallel and *B* is constant through the path.

In category C we grouped the answers which do not consider Gauss's law or Ampere's law, but instead are based on the general principle that the electrical field or magnetic field is generated by all of the charges or currents in the space without providing any further justifications. In our opinion, this type of answer does not justify the claim it makes. One example of this type of answer is as follows.

- Example 13 (Q2)
  'The field that we calculate when applying Gauss's law is the one generated by the charged plane, because the field formula works for the entire plane.'
- How do students use flux and field circulation operators and consider the field pattern of symmetry?

In question 1, proper reasoning on the question would lead students to indicate that the condition $\Phi = 0$ does not necessarily imply that the field is null at each point on the surface. Question 6 is similar to question 1 but using the context of magnetic fields and Ampere's law. In this question, the correct interpretation of Ampere's law would lead students to reject the argument which is offered.

In questions 3 and 7, it is necessary to take into account the patterns of field to apply Gauss's and Ampere's laws. Students have to reason that these laws are an easy path to obtaining the value of field (because direct integration is easy) when there are some symmetry conditions between the pattern of field and choosing surfaces and paths. The students' answers are shown in table 2.

We have grouped correct answers into category A; some examples of this category are as follows.

- Example 1 (Q1)
  'Flux is defined as $\Phi = \oiint \vec{E} \cdot d\vec{S}$ and therefore if vectors *E* and d*S* are perpendicular, flux can be equal to zero without the field *E* being so.'
- Example 2 (Q7)
  'The symmetry conditions for the field in paths (1) and (2) are completely different. In path (1), the field is constant in all points and the integral is simple. In path (2), the integral is complex and the field cannot be considered as constant. I do not agree with student E2.'

For questions 1 and 6, category B comprises the answers which indicate that the condition flux $\phi = 0$ or circulation $\Gamma = 0$ implies that the field is null. Students reason in accordance with two variants of reasoning. One of them (more common than the other) includes answers which explain that, because the flux/circulation is null, the charged/current enclosed is zero

and therefore the field will be zero, which is consistent with the idea that only internal charges/currents on the Gaussian surface/by the Amperian path produce an electrical field on the points of the surface/path.

- Example 1 (Q1)

  'If the flux is zero, it is verified that $0 = \oiint \vec{E} \cdot d\vec{S}$, there is no charge and therefore the field on the Gaussian surface is zero.'
- Example 2 (Q6)

  'If we apply Ampere's law: $0 = \oint \vec{B} \cdot d\vec{l}$ there is no current to create B, and so $B = 0$.'

In this case, it seems as if the students are simplifying a situation which requires complex arguments based on constructing simple inferences such as flux/circulation zero implies field zero (a cause produces an effect) in the form of a linear chain, using the law's formula as a link (functional reduction). Let us look at an example of an answer from one of the interviews.

- Interviewer: Why do you say that the field on the Gaussian surface is zero? (Q1)

  Student: If the flux is zero, that means that there is no charge, doesn't it? Well, in Gauss's law, flux is proportional to charge, and if the charge is zero, this indicates that there is no field. In other words, if we use Gauss's law in this case, then if the flow is zero, the charge is zero and there is no field.

The second form of students' reasoning seems to correspond to a strategy commonly used in class but which has a very specific field of validity (symmetry conditions to be B constant in the Amperian path). One standard answer of this kind of reasoning is as follows.

- Example 3 (Q6)

  'If we apply Ampere's law: $0 = \oint \vec{B} \cdot d\vec{l} = B \oint dl \Rightarrow B = 0$ so I believe the student is right.'

In the interview for question 1, students do not analyse the field of validity of Gauss's law and use it in a non-critical manner, as we can see in part of the following interview.

- Interviewer: Why do you say that the field on the Gaussian surface is zero? (Q1)

  Student: If we look at Gauss's law, it is clear. If the flow is zero, the following equation is fulfilled: $0 = \oiint \vec{E} \cdot d\vec{S} = E \oiint dS \Rightarrow E = 0$ and therefore the field on the Gaussian surface is zero.

In the reasoning followed by the students, they do not establish the need for field E to be constant in value throughout the Gaussian surface and for the angle formed with each differential element of the area to also be constant in such a way that it can be taken out of the integral. It seems to respond to a strategy commonly used in class but which has a very specific field of validity. However, the students apply it in a general manner, demonstrating functional fixedness upon one strategy.

As for the results of questions 3 and 7, it should be pointed out that forms of reasoning converged. In general, students' answers do not take into account the pattern of field lines and so they suppose that the field is constant along the surface or the path. This form of reasoning is used by the majority in Q3 and Q7 where most students do not take into account the symmetry conditions which the field must fulfil in the Gaussian surface or Amperian line to obtain a mathematically simple solution. These results are convergent with one of the last forms of reasoning that we explained in the category B of questions 1 and 6. Let us look at a few examples.

- Example 7 (Q7)

  'Both students are correct as if we apply Ampere's law we obtain

  $$\oint_{(1)} \vec{B} \cdot d\vec{l} = \mu_0 I \Rightarrow B_A l = \mu_0 I \quad \text{and} \quad \oint_{(2)} \vec{B} \cdot d\vec{l} = \mu_0 I \Rightarrow B_A l = \mu_0 I.'$$

- Example 8 (Q3)

  'In any closed surface (Gaussian surface) we can apply Gauss's law: $\oiint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$ so the electric field will be $E = \frac{q}{S\varepsilon_0}$. I agree with student.'

It has been shown that fixedness to a formula leads students to confuse field operators and the field itself (i.e. when the flux or the circulation is zero, it is deducted that the field value is zero in the Gaussian surface or in the Amperian path). Most of the students find it difficult to distinguish clearly between the field operators and the field itself. They show a lack of meaning of the flux and field circulation operators, as well as a lack of meaning for the field itself. The results agree with those obtained by Albe *et al* [14]. These authors state that 'the physical definition of magnetic flux appears to be confused for undergraduates and pre-service physics teachers' (p 201).

5. Discussion and implication for physics teaching

The results obtained seem to show that, after instruction, most of students mechanically apply reasoning based on incorrect strategies such as functional reduction and functional fixedness which evidence the lack of meaning for flux and circulation operators and for the field itself. We summarize these forms of reasoning in the following chart:

Non-scientific forms of reasoning	Examples of standard answers
1. Functional fixedness on the formula: answers which assume that the field is constant along the surface or the path in all the situations where Gauss's and/or Ampere's law is applied.	1. 'If $\Phi = 0$, then $0 = \oint \vec{E} \cdot d\vec{S} = E \oint dS \Rightarrow E = 0$.'
2. Functional reduction based on drawing simple conclusions from complex phenomena.	2.1. 'If the flow is zero and the $\vec{E}$ and $d\vec{S}$ vectors are not perpendicular, the field at any point of the surface must be zero, because $\oint \vec{E} \cdot d\vec{S} = 0$.'
2.1. When flow or circulation is zero it is deduced that the field at any point of the Gaussian surface or Amperian line is zero.	2.2. 'Ampere's law states that only the intensity that flow through the Amperian line create the field'.
2.2. The only field sources are those inside the Gaussian surface or Amperian line.	
3. Preparation of 'ad hoc' explanations for each case. Reasoning is not in accordance with the search for generality and systematicity characteristics of the scientific method, which imposes stricter and more rigorous conditions.	3. 'The field calculated is only in respect of the Gaussian surface, but as the plane has a uniform density of field, a generalization may be made for the rest of the plane.'

We have seen the low level of students' reasoning in both the area of electricity and the area of magnetism. We can interpret that these incorrect forms of reasoning are framed within an inappropriate understanding of the field model which affects a great variety of both electrical (Gauss's law) and magnetic (Ampere's) phenomena. Students present a lack of epistemological relevance for the model that scientists use to interpret electromagnetic phenomena, and so there is a lack of context where Gauss's and Ampere's laws are applied. A partial explanation of these results could be the strategies used in traditional teaching which

consider that the pattern of field lines is obvious and start discussing the convenience of Gauss's or Ampere's laws for a proposed surface or path.

Teachers should keep in mind that students already have ways of approaching questions and problems, and these are prototypical of a common sense methodology (i.e. repeating a strategy mechanically, thinking through the formula, etc); therefore, teaching should be planned more according to scientific epistemology. Thus, to avoid the common tendency towards functional fixedness in a strategy (i.e. field always constant in the application of Gauss's and Ampere' laws), it may be very useful to propose a different task in a teaching sequence that encourages students to draw up the field patterns and to establish a 'criteria of acceptability' for different forms of Gaussian surfaces and Ampere pathways. In this way, students must use different strategies for the field sources and their pattern of symmetry, for example discussion about the feasibility of the strategy based on the field model (Gauss's and Ampere's laws) or on the model of action at a distance (Coulomb's law), in relation to the symmetry of the patterns of field lines.

It will be necessary to design teaching sequences that stimulate students to analyse the field line patterns for different charges or current configurations. This analysis should encourage students to take into account all field sources and to avoid functional reduction based on the formula. These activities will encourage students to search for all the sources making up the field pattern and discuss what the pattern would be if only the charges or currents enclosed by the surface or path were taken into account.

Designing tasks that should involve students evaluating wrong methods of reasoning when determining the field sources or the solving strategy may bring students to a global rational of the model that it is used. For example, a first task can be proposed on 'pattern field dependence'. This activity aims to emphasize the factors that may influence choosing a strategy to calculate the field. After stating the variables that may influence the situation (field sources, patterns of lines, symmetry in relation to 'ad hoc' surface or path, etc), a strategy will be presented to calculate the value of the field. In this second task, students' reasoning will be stressed when explaining how this specific functional analysis is done and whether it has been developed correctly. Designing, implementing and evaluating a teaching sequence for these topics based on students' epistemological difficulties, which have been detected, and on a global rational compared to the field model, which is taught in introductory physics courses, will be the objective of our next studies.

Appendix

A.1. Questionnaire

Q1. If the electric field flux across a closed surface is zero, does it mean that the electric field on each point of the surface is zero?

yes . . . .   no . . . .   I don't know . . . .
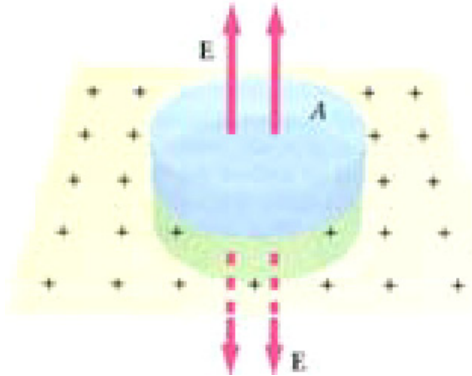
Justify your answer.

Q2. Consider an infinite sheet, with a surface charge density: σ. Is the electric field you determine from Gauss's law:

 (a) the field produced by all the elements of charge in the sheet?

yes . . . .   no . . . .   I don't know . . . .

(b) the field produced by the charge within the Gaussian surface? (The Gaussian surface we refer to is the cylindrical one used in textbooks, see figure.)
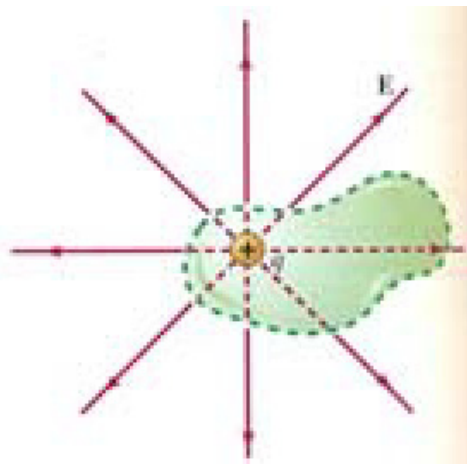
yes . . . .   no . . . .   I don't know . . . .

Justify your answer.

Q3. A student finds the electric field on the Gaussian surface that surrounds the charge q (see figure), using the following reasoning: according to Gauss's law the total electric flux through the surface is

$$\oiint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0} \text{ carrying out direct integration: } ES = \frac{q}{\varepsilon_0} \Rightarrow E = \frac{q}{S\varepsilon_0}.$$

Do you agree with the student?
Justify your answer.

Q4. We consider a long solenoid, where we assume that as long as we are far from the ends, the magnetic field inside the solenoid is fairly uniform and the magnetic field outside is very small. As you know, in these conditions we can calculate the field inside the solenoid by applying Ampere's law. The Amperian line of integration will be the line shown in the diagram below. From this we can conclude that
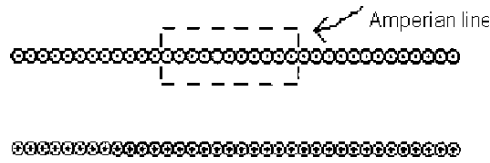
(A) The calculated magnetic field is caused by all the loops of the solenoid.
(B) The calculated magnetic field is caused only by the loops inside the Amperian line.
(C) Another answer.

Explain your answer.

Q5. Here are two very long parallel straight wires, a distance d apart. The left wire carries a conventional current I_1 and the right wire carries a conventional current I_2 in the same direction. A student uses Ampere's law and says the magnetic field at any point of the circular path of radius R is $B = \mu_0 I_1/2\pi R$. Do you agree with this student?
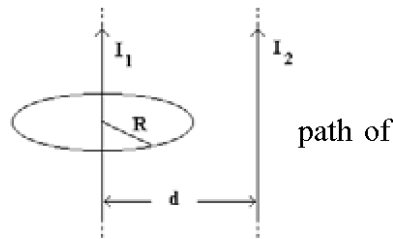
Q6. An intensity of current, **I** amps, flows through each of the two 'infinite' threads. These threads are perpendicular to the plane of the paper and in one the current is outward whereas in the other it is moving inward. Trajectory (1) is circular, it moves anti-clockwise and it contains two threads.

A student, using trajectory (1), applies Ampere's law and concludes that the circulation of the fields being nil, the field B is also nil at all points of the trajectory (1). Do you agree with this student?
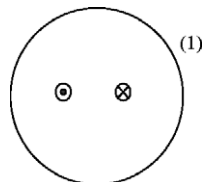
Justify your answers.

Q7. Imagine a very long wire along which current **I** circulates; this thread of current is perpendicular to the plane of paper and outward. A student, E1, applies Ampere's law to calculate the magnetic field created by this current at A, using the circular trajectory (1) which contains point A and through the centre of which passes the thread of current, and comes to the conclusion that the value of the field is: $B_A = \mu_0 I/\ell$, where ℓ is the length of the circumference corresponding to trajectory (1). Another student, E2, does the same thing but using a closed non circular trajectory (2), which also contains point A, coming to the conclusion that the value of the magnetic field in A is: $B_A = \mu_0 I/L$, where L is the length of the trajectory (2).

Explain the reasons why you agree with student E1, or with E2, or with both, or with neither of them.
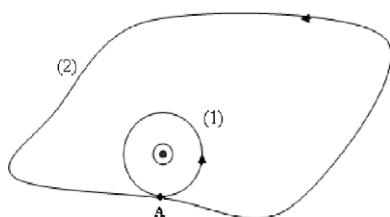
Note. Trajectories (1) and (2) are located on the plane of the paper.

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