1996

Students' Understanding of the Interaction Between Charged Conductors.

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3. **Rule 3:**

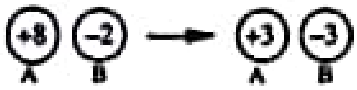

Fig. 2.7: Rule 3 - The Sphere Test.

Transfer between two oppositely charged spheres results in a zero net charge on the two spheres.

A student who uses this rule in case 2 explains how he arrives at the charges shown in Fig. 2.7:

> "Since the spheres are oppositely charged the net charge will be equal to zero. Therefore one sphere will be +3 and the other −3."

The student is consistent in applying this rule to case 3 and case 4. In case 3, the student says:

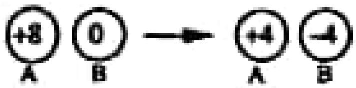

Fig. 2.8: Rule 3 as applied to Case 3.

> "Because the net charge has to be zero, so if one is +4 the other must be −4."

In case 4, the student states:

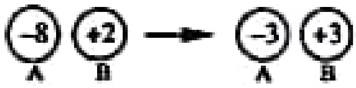

Fig. 2.9: Rule 3 as applied to Case 4.

> "Opposite charges, since it is a conductor one sphere will be + and the other −."

However when the two spheres have like charges as in case 1, the student divides the net charge between the two spheres.

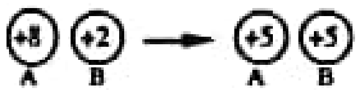

Fig. 2.10: Rule 3 is not applied to Case 1.

> "If they are made to touch each other eventually the charges will balance out and come to equilibrium. Because they are like charges."

The three rules described above were major rules of transfer, i.e., they were used by a large number of students. There were several other rules listed in Table 2.1 that were

At least 40% of the students who used Rule 2 at least once, applied it consistently to cases 2, 3, and 4 of the sphere test. Many of the students who did not use Rule 2 for case 3 tended to arrive at the correct answer. When applied to case 3, the rule may be stated as:

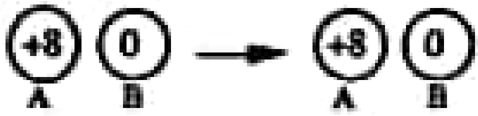

Fig. 2.6: Rule 2 as applied to Case 3 in the Sphere Test

There is no transfer of charge between a charged sphere and a neutral sphere.

The students who apply this rule to case 3 think that the initial state is stable and therefore will remain unchanged as shown in Fig. 2.6. One of the students who uses this rule supports his answer with the following explanation:

> "A is unable to gain charge from B to work toward neutrality and B is already neutral so there is no charge."

It appears that the neutral state is regarded as a state of equilibrium. To some extent, this may be because many students do not seem to understand what is meant when a sphere is said to have a charge of 0μC. Instead of being composed of an equal number of positive and negative charges, neutral objects are sometimes viewed literally as objects that contain no charges at all, e.g.,

> "There is no difference. Since B has no charges it doesn't affect the charge on A"

Even when students do recognize the existence of charges within a neutral object, many do not recognize that electrostatic interactions can act on these charges, e.g.,

> "Nothing can happen because there are no extra electrons."

In summary, if one of the spheres is neutral then many students believe that there is no transfer of charge between the spheres.

2. Rule 2:

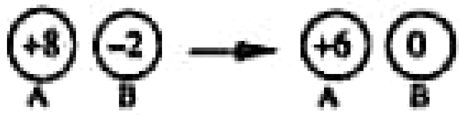

Fig. 2.5: Rule 2 - The Sphere Test

Transfer between two oppositely charged spheres occurs until one of the spheres is neutral.

This rule (illustrated in Fig. 2.5) can be summed up in the following quote by a student who previously had used Rule 1 to describe the transfer in the case when the spheres were both initially charged positively. When considering spheres that initially have charges of opposite sign, the student states that charge will transfer until one of the spheres is neutral.

> "Sphere B can only take on enough + charge to neutralize its −2 charge and any excess charge would create the situation from the first case."

The phrase "the situation from the first case", refers to the student's use of Rule 1 to answer the previous question involving two positively charged spheres. Rule 2 is based on the premise that the transfer of charge can take place only when there is a force of attraction between the charges in the two spheres. When the sphere with a charge +8μC touches a sphere with a charge of −2μC, there is a transfer of charge until the charge on one of the two spheres (usually the one with the smaller charge) is neutral. The students reason that since there is no (excess) charge in a neutral sphere, there is no force of attraction between the two spheres and there is no transfer at this point. To quote another student talking about the same case:

> "I think that the electrons will shift over to the +8 sphere until sphere B has no net charge."

When one of the two spheres becomes neutral, the flow of charge between the spheres stops and an "equilibrium" is reached.

students used different rules to explain their answers to different cases. This is reflected in the numbers in columns four and five which add up to totals larger than the number of students who took the test.

D. Major Rules of Transfer in the Sphere Task:

Rules used by a considerable fraction of the class will be referred to as the "Major Rules of Transfer". There are three such rules in the Sphere Test. They are the first three rules that appear in Table 2.1 and will be discussed below. The other rules of transfer will be listed in Table 2.1 but will not be described in detail. In discussing the rules we have frequently quoted students. The quotes have been edited for spelling and grammar.

1. Rule 1:

There is no transfer of charge between two spheres with charges of the same sign.

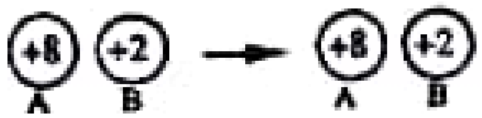

Fig. 2.3: Rule 1-The Sphere Test

As is shown in Table 2.1, 33% of the students before instruction and 26% of the students after instruction responded that there is no transfer between two positively charged spheres when they are made to touch each other for a long time and separated. The quote given below is representative of the explanation given by most students.