

AP1 Electricity

1. A student wearing shoes stands on a tile floor. The student's shoes do not fall into the tile floor due to

- (A) a force of repulsion between the shoes and the floor due to macroscopic gravitational forces.
- (B) the electrical repulsion between the shoes and the floor due to interatomic electric forces.
- (C) the strong nuclear force creating a force of repulsion between the atoms in the student's shoes and the atoms in the tile.
- (D) The weak nuclear force creating a force of repulsion between the leptons in the student's shoes and the nucleons in the tile.

Answer: (B) the electrical repulsion between the shoes and the floor due to interatomic electric forces.

Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces.

EK: 3.C.2 Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge. 3.C.4 Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, and spring.

SP: 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 3.C.2.2 The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. 3.C.4.1 The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces (interatomic electric forces). 3.C.4.2 The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions.

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2. A neutral baryon is composed of three quarks: two down quarks which each have a charge of $-\frac{1}{3}e$, where e is the elementary charge, and an up quark. What is the charge on an up quark?

- (A) $+\frac{1}{3}e$
- (B) $-\frac{1}{3}e$
- (C) $+\frac{2}{3}e$
- (D) $-\frac{2}{3}e$

Answer: (C) $+\frac{2}{3}e$

The entire baryon is neutral, so the sum of charges from its constituent particles must be zero due to the law of conservation of charge. Therefore, the charge on the up quark must be (C) $+\frac{2}{3}e$.

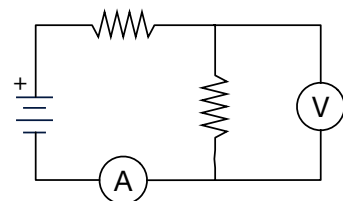
EK: 1.A.1 A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object. 1.B.1 Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.

SP: 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

LO: 1.B.1.2 The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits.

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3. Following a period of extended use, the battery-powered circuit at right no longer functions. What are reasonable explanations for the circuit no longer functioning? Select the two best answers.



- (A) The electrons from the battery are used up as the circuit “runs out of juice.”
- (B) The potential difference supplied by the battery has degraded.
- (C) The current in the circuit has been converted to heat in the resistors.
- (D) The battery can no longer supply sufficient power to operate the circuit.

Answers: (B) and (D)

Circuits do not run out of juice as electrons are used up -- this would violate the law of conservation of charge, so A cannot be an answer. The current in the circuit is not converted to heat, as current is a flow of electrons, and the law of conservation of charge prohibits the destruction of that charge, therefore C cannot be an answer. Both B and D are correct.

EK: 1.B.1 Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system. 5.C.3 Kirchhoff’s junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit.

SP: 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.5 The student can evaluate alternative scientific explanations.

LO: 1.B.1.1 The student is able to make claims about natural phenomena based on conservation of electric charge. 5.C.3.1 The student is able to apply conservation of electric charge (Kirchhoff’s junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed.

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4. The magnitude of the force of attraction between two point charges is F . If the magnitude of each point charge is doubled, and the distance between the charges is doubled, what is the new magnitude of the force of attraction between the point charges?

- (A) $F/2$
- (B) F
- (C) $2F$
- (D) $4F$

Answer: (B) F

Doubling each charge doubles the force, for a total force of $4F$. Then, doubling the distance cuts the force by a factor of 4 due to the inverse square nature of the charge separation, bringing the net force back down to its original value F .

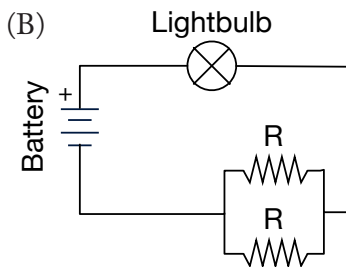
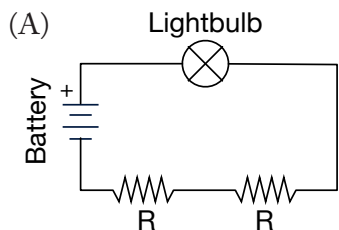
EK: 3.C.2 Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 3.C.2.1 The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges.

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5. Consider two circuits, A & B, shown below. Both have identical resistors of resistance R and identical light bulbs.



Correct statements about the bulbs in each circuit include which of the following? Choose 2 statements.

- (A) Bulb A and Bulb B are the same brightness because the resistances are all the same.
- (B) Bulb B has a greater voltage drop across it than Bulb A.
- (C) The currents through each bulb are the same as the currents through their respective batteries.
- (D) Bulb A has a greater current through it than Bulb B.

Answer: (B) and (C)

(A) is incorrect because the equivalent resistances of the circuits are different because of the differing series/parallel resistor configurations.

(B) is correct because the resistance of the resistor network in circuit B is less than that of A because the resistors are in series, leaving more of the battery's voltage to be dropped across the lightbulb in circuit B.

(C) is correct because in both cases, the current through the battery also flows through the light bulb due to conservation of charge / Kirchhoff's Current Law.

(D) is incorrect because the effective resistance of circuit A is greater than circuit B, therefore there is less current through Bulb A.

EK: 5.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 5.C.3.1 The student is able to apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed.

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6. A scientist claims that she has captured and isolated a top quark and measured the magnitude of its charge as 5.33×10^{-20} C. Which of the following best explain why this claim should be doubted? Select two answers.

- (A) The magnitude of the charge on a top quark is two-thirds of an elementary charge, which is twice as large as the charge the scientist measured.
- (B) The smallest observed unit of charge that can be isolated is the elementary charge.
- (C) Particles cannot have a charge less than an elementary charge.
- (D) It is physically impossible to measure any charge smaller than an elementary charge.

Answer: (A) and (B) are the correct answers.

- (A) the magnitude of the charge on a top quark is $\frac{2}{3}$ of an elementary charge.
- (B) The smallest observed unit of charge that can be isolated is the elementary charge.
- (C) Is incorrect because particles can have a charge less than an elementary charge, but they cannot be isolated.
- (D) Is incorrect because charges smaller than an elementary charge can be measured.

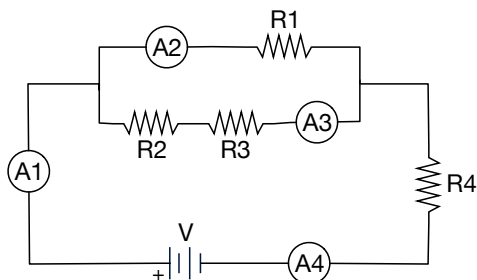
EK: 1.B.3 The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.

SP: 1.5 The student can reexpress key elements of natural phenomena across multiple representations in the domain.
6.1 The student can justify claims with evidence. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

LO: 1.B.3.1 The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated.

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7. The circuit schematic below shows four resistors and four ammeters connected to a voltage source, V . It is known that the current in ammeter A_1 is 6.0 A , and the current in ammeter A_2 is 2.0 A .



I. Which of the following must be true statements about the current through resistors R_2 & R_3 ?

- (A) The current through both must be 4.0 A because they have the same voltage drop across them
- (B) The current through both must be 4.0 A because they are in series with each other
- (C) The current through both must be 2.0 A because they share the current in the lower branch
- (D) The current cannot be determined without information about the resistances of R_2 & R_3

II. If the resistance of R_4 is given, what other information is necessary to determine the value of V , the voltage of the battery?

- (A) the reading of ammeter A_4 and resistance of R_2
- (B) the reading of ammeter A_4 and resistance of R_1
- (C) resistance of R_1
- (D) resistances of R_1 , R_2 & R_3

I. Answer: (B)

- (A) Incorrect because one cannot assume the resistances (and therefore the voltage drops) are the same
- (B) Correct because the lower branch must draw 4 A to conserve charge and the relative currents are the same irrespective of resistance values
- (C) Incorrect because there is no sharing of current in series
- (D) Incorrect - see (b) above

II. Answer: (C)

- (A) Incorrect because R_2 & R_4 do not complete a path in which the loop rule can be applied
- (B) Incorrect because even though R_1 & R_4 complete a loop, A_4 is superfluous since it's in series with A_1
- (C) Correct because R_1 & R_4 complete a loop and $V = I_1 R_1 + I_4 R_4$, where I_1 is known from A_1
- (D) Incorrect because knowledge of R_1 (or R_2 & R_3) is all that is necessary, not both

EK: 5.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits. 5.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit.

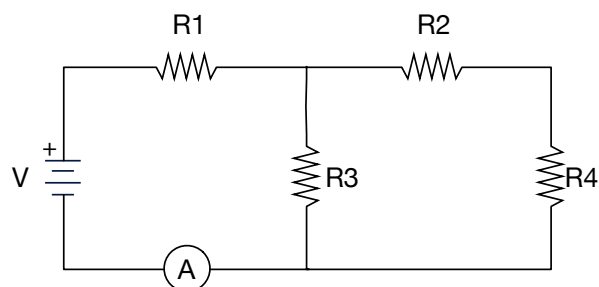
SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.

LO: 5.B.9.3 The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. 5.C.3.1 The student is able to apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed.

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8. In the circuit shown at right, resistors R1, R2, R3, and R4 all have the same value of resistance. Removing which resistor from the circuit would result in the smallest change to the ammeter reading? Select two answers.

- (A) R1
- (B) R2
- (C) R3
- (D) R4



Answers: (B) R2 and (D) R4

The initial current flow in the circuit is $0.6 V/R$. Removing either R2 or R4 from the circuit (or both) effectively makes the circuit a series circuit with just R1 and R3, for a current flow of $0.5 V/R$, a reduction of $0.1 V/R$. Removing R1 from the circuit opens the circuit and no current flows, and removing R3 creates a series circuit with an equivalent resistance of $3R$, for a total current flow of $0.33 V/R$. Therefore, removing R2 and/or R4 results in a circuit with the least change in current flow through the ammeter.

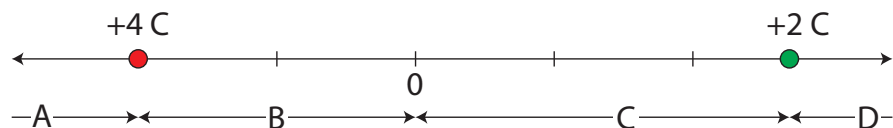
EK: 5.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits. 5.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit.

SP: 1.3 The student can refine representations and models of natural or man-made phenomena and systems in the domain. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 3.3 The student can evaluate scientific questions.

LO: 5.B.9.3 The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. 5.C.3.3 The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit.

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9. A $+4\text{ C}$ point charge and a $+2\text{ C}$ point charge are situated on an axis as shown in the diagram. In which region can you place an unknown point charge and have it remain at rest?



Answer: C

In order for the point charge to remain at rest, the net force on the charge must be zero, therefore the force due to the $+4\text{ C}$ charge must be equal in magnitude and opposite in direction to the force due to the $+2\text{ C}$ charge. In regions A and D, the forces due to the charges are in the same direction, so those regions can be eliminated. In order for the magnitudes of the forces to be equal, the point must be closer to the $+2\text{ C}$ charge than the $+4\text{ C}$ charge, therefore region C must be the correct answer.

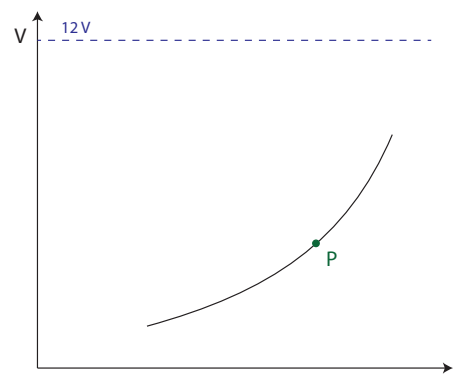
EK: 3.B.1 If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. 3.C.2 Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

LO: 3.B.1.1 The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension. 3.C.2.1 The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges.

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10. The graph at right shows a plot of voltage versus current for a filament lamp. The 12 V dashed line shows the voltage setting of the power source.

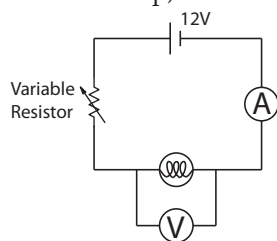


(a) Explain how the graph shows that the filament *does not* obey Ohm's Law.

(b) Give a physical explanation of why the filament lamp does not obey Ohm's Law.

(c) Explain how one would determine the resistance of the filament for point P on the graph.

(d) In order to gather the data to make the graph shown above, a variable resistor was placed in series with the filament lamp, and both were connected to a 12-volt source as shown in the schematic below.



Explain why using a variable resistor in series with the lamp

i. will not allow a reading of 0 V across the filament lamp.

ii. will not allow a reading of 12 V across the filament lamp.

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Answer:

- (a) Ohm's law states that the relationship b/w V & I is linear and proportional. The graph shows a non-linear plot, thus does not obey Ohm's law;
- (b) As the current increases the temperature of the filament increases. As the temperature increases the resistance increases.
- (c) The resistance is found by taking the ratio of voltage to current at point P.
- (d)
 - i. To get a reading of 0 V across the bulb, the variable resistor would have to have an infinite resistance. An infinite resistance in series with the bulb would leave 0 V across the rest of the circuit.
 - ii. To get a reading of 12 V across the filament lamp there would have to be 0 resistance in the variable resistor, the wires and the voltage source; this is not physically possible.

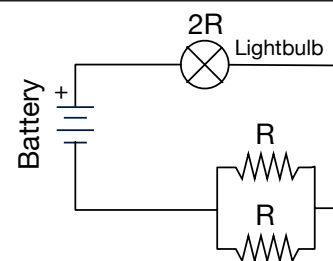
EK: 5.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits. 5.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit.

SP: 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.

LO: 5.B.9.3 The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. 5.C.3.1 The student is able to apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed.

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11. The circuit at right shows a light bulb of resistance $2R$ connected to a battery with no internal resistance and two resistors, each with a resistance R .



(a) Which component has more current passing through it, the light bulb or either of the resistors? Give a detailed explanation with supporting equations if necessary.

(b) Develop an expression for the voltage drop across the light bulb as a fraction of the battery voltage, V . Give detailed support.

(c) Suppose one of the resistors, R is removed from the circuit, without reconnecting the wires. Which component will develop more power, the remaining resistor or the light bulb? Justify your answer.

Answer:

- (a) The light bulb has more current than either bulb because the bulb is in series with the battery, while the resistors are in parallel. All the current passes through the bulb and it splits equally between both resistors.
- (b) $4/5 V$. The total current in the circuit will be $2V/5R$, therefore the potential drop across the bulb, by ohm's law, is equal to the product of the current through the bulb and the bulb's resistance, or $V_{\text{bulb}} = (2V/5R) \times (2R) = 4/5 V$.
- (c) The light bulb will develop more power than the resistor. Removing one resistor will put the remaining resistor in series with the bulb, so both the bulb and the resistor receive the same current. The bulb, however, has twice the resistance of the resistor, which will therefore develop more power since $P=I^2R$.

EK: 5.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 5.B.9.3 The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch.