AP Physics 1- Electrostatics and Electrical Currents Problem Set [Solutions Video]

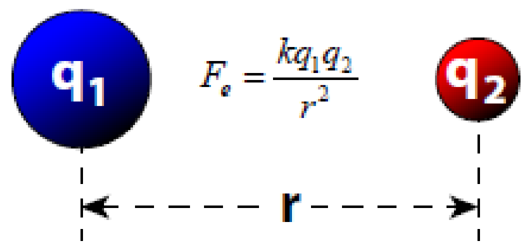
FACT: In physics, the charge on an object is represented with the symbol *q*. The fundamental unit of charge is the coulomb [C], which is a very large amount of charge. Compare that to the magnitude of charge on a single proton or electron, known as an elementary charge (e), which is equal to 1.6×10^{-19}coulomb. It would take 6.25×10^{18} elementary charges to make up a single coulomb of charge. While the AP Exam will probably not ask you to do many calculations on this topic, it is essential to understand the mathematical reasoning behind the computations.

Q1. An object possessing an excess of 6.0×10^{6} electrons has what net charge?

Q2. An alpha particle consists of two protons and two neutrons. What is the charge of an alpha particle?

Q3. What is the net electrical charge on a magnesium ion that is formed when a neutral magnesium atom loses two electrons?

Q4. A student has a neutrally charged glass rod and a neutrally charged silk cloth. When the student rubs the silk cloth on the glass rod, the rod acquires a net positive charge of 45 µC. (a). What is the charge on the silk cloth after the student performs this experiment? (b). How many electrons were transferred?



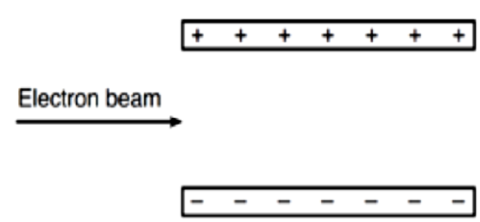
FACT: The magnitude of the electrostatic force is described by Coulomb's Law, which states that the magnitude of the electrostatic force (F_e) between two objects is equal to a constant, k, multiplied by each of the two charges, q_1 and q_2, and divided by the square of the distance between the charges (r^2). The constant k is known as the electrostatic constant and is given as $k=9.0\times10^{9}$ $N{\cdot}m^2/C^2$. See image to the right.

FACT: Formally, a positive value for the electrostatic force indicates that the force is a repelling force, while a negative value for the electrostatic force indicates that the force is an attractive force. To determine the direction of the force vector (F_e), once you have calculated its magnitude, use common sense to tell you the direction on each charged object. If the objects have opposite charges, they attract each other, and if they have like charges, they repel each other. The force between the particles forms a Newton's third law force-pair.

Q5. Three protons are separated from a single electron by a distance of 1×10^{-6} m. Find the electrostatic force between them. Is this force attractive or repulsive?

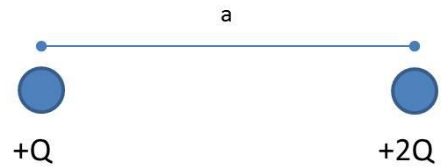
FACT: *Semi-quantitative Reasoning*- both Newton's Law of Universal Gravitation and Coulomb's Law follow the inverse-square relationship, a pattern that repeats many times over in physics. The further you get from the charges, the weaker the electrostatic force. If you were to double the distance from a charge, you would quarter the electrostatic force on a charge. Expect to see questions on the exam that require this type of semi-quantitative reasoning.

Q6. A beam of electrons is directed into the electric field between two oppositely charged parallel plates, as shown in the diagram. In which direction is the electrostatic force exerted on the electron beam by the electric field?



Q7. Consider two small spheres, one carrying a charge of +1.5 nC and the other a charge of – 2.0 nC, separated by a distance of 1.5 cm. Find the electrostatic force between them and describe their interaction.

Q8. Two charges are separated by a distance, *a*, as shown in the diagram below. (a). Which is greater, the force of +Q charge on the +2Q charge, or the force of the +2Q charge on the +Q charge? (b). In terms of the given variables and fundamental constants, determine the magnitude and direction of the force of the +2Q charge on the +Q charge. (c). By what factor would the force calculated in (b) change if the distance between the charges was increased to 3*a*? (d). Now the +Q charge is replaced by a negative charge of the same magnitude, and the distance between the charges is returned to *a*. Describe how the magnitude and direction of the force exerted between each charge on the other will change from the original situation.

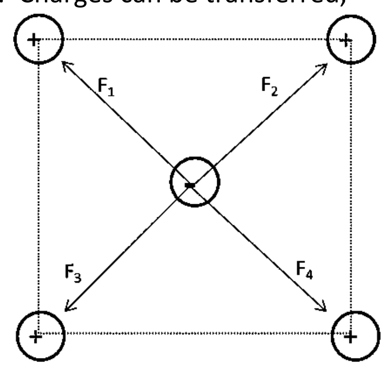


Q9. The centers of two small charged particles are separated by a distance of 1.2×10^{-4} meter. The charges on the particles are $+8.0\times10^{-19}$ coulomb and $+4.8\times10^{-19}$ coulomb, respectively. (a) Calculate the magnitude of the electrostatic force between these two particles. (b) Sketch a graph showing the relationship between the magnitude of the electrostatic force between the two charged particles and the distance between the centers of the particles.

FACT: On the AP Exam**,** you must be able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. As already discussed, there are only two types of elementary charges (positive-negative) and no smaller charge has ever been isolated. They attract or repel each other, depending on the magnitude of the charge and the distance between the objects.

FACT: The total amount of charge in a system is always the same and on the AP Exam you will need to be able to make claims about natural phenomena based on conservation of electric charge. Equal amounts of + and – charges can cancel each other and become neutral, but they still exist on the object as protons and electrons. Charges can be transferred, but the total amount is constant in the system.

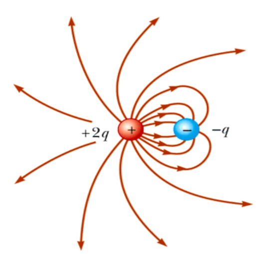
Q10. Consider four equal, positive point charges that are situated at the vertices of a square. Find the net electric force on a negative point charge placed in the square's center.



Q11. Considering Q10, if the two positive charges on the bottom were removed, what would be the net electric force on the negative charge?

FACT: Similar to gravity, the electrostatic force is a non-contact force, or field force. Charged objects do not have to be in contact with each other to exert a force on each other. What is the big difference between electrostatics and gravity? The gravitational force can only attract, while the electrostatic force can both attract and repel. The electric field strength and the gravitational force both follow the inverse-square law relationship. They are inversely related to the square of the distance. However, the magnitude of the electrostatic force is greater than the magnitude of the gravitational force. There will be a question on the AP Exam comparing these two types of forces.

FACT: When considering electric fields, the vectors point away from positive charges and toward negative charges and electric field lines never cross and are determined by vector addition. Please examine the diagram to the right.



FACT: Electric current is the flow of charge. Electric current (I) is measured in amperes (A), or amps, and can be calculated by finding the total amount of charge (Δq), in coulombs, which passes a specific point in a given time (t). Electric current can therefore be calculated as: $I = \frac{\Delta q}{t}$. Electric currents flow from high electric potential to low electric potential, just like water molecules in a concentration gradient.

Q12. A charge of 30 Coulombs passes through a 24-ohm resistor in 6.0 seconds. What is the current through the resistor?

Q13. A charge is flowing at the rate of 2.50×10^{16} elementary charges per second. What is the current?

Q14. The current through a lightbulb is 2.0 amperes. How many coulombs of electric charge pass through the lightbulb in one minute?

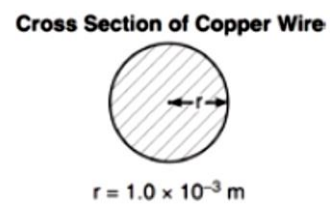
Q15. The current traveling from the cathode to the screen in a television picture tube is 5.0×10^{-5} amperes. How many electrons strike the screen in 5.0 seconds?

FACT: A material's ability to conduct electric charge is known as its conductivity. *Resistance* (R) is an object's ability to impede the flow of charge and the units of resistance are ohms (Ω). A material's ability to resist the movement of electric charge is known as its *resistivity* (rho; ρ) and is measured in ohm-meters (Ω•m) and is expressed as: R = $\frac{\rho L}{A}$ where L is the length (m) and A is the cross-sectional area of the object, A = $2\pi r^2$ (m^2). As to not confuse these two related terms I will use them in a sentence: Glass has a much greater intrinsic resistance than copper because it has a greater resistivity.

Q16. A 3.50-meter length of wire with a cross-sectional area of 3.14×10^{-6} m^2 at 20° Celsius has a resistance of 0.0625 Ω. Determine the resistivity of the wire.

Q17. A length of copper wire and a 1.00-meter length of silver wire have the same cross-sectional area and resistance at 20°C. The resistivity of copper is 1.72×10^{-8} Ω•m and the resistivity of silver is 1.59×10^{-8} Ω•m. Calculate the length of the copper wire.

Q18. A 10-meter length of copper wire is at 20°C. The radius of the wire is 1.0×10^{-3} meters as shown in the diagram to the right. Calculate the resistance in the wire.



FACT: Ohm's Law relates these properties into an intuitive expression: R = $\frac{V}{I}$; which can obviously be rearranged as $I = \frac{V}{R}$ and V = IR, where V is the potential difference, or voltage (volt). When we consider any of these expressions, say $I = \frac{V}{R}$, it's easy to see that the current flowing through a conductor or resistor (amps) is equal to the potential difference across the object (volts) divided by the resistance of the object (ohms). If you want a large current to flow, you require a large potential difference (such as a large battery), and/or a very small resistance. Or if we consider V = IR and a constant voltage, we see that if the resistance decreases, the current must increase for the voltage to remain the same.

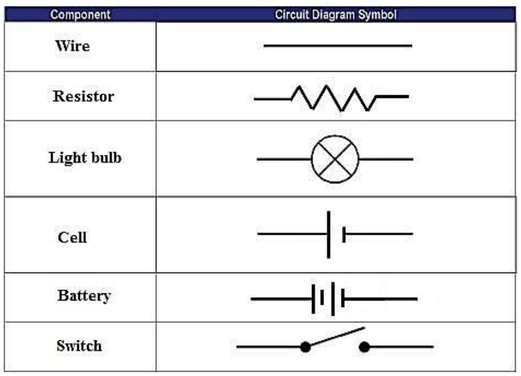
FACT: *River Analogy*- A river moves water at a given rate, just as current (I) moves positive charge at a given rate (I =1 C/s = 1A). As a river meanders back and forth it slows the flow of water, just as resistance (R) impedes the passage of electric current (R = 1 V/A = 1 Ω). A river flows from higher ground to lower ground, just as voltage (V) provides the potential difference as *positive* charges move from areas of higher potential to lower potential. Our river will flow faster as the gradient increases, just as electric charges will flow faster as the voltage increases.

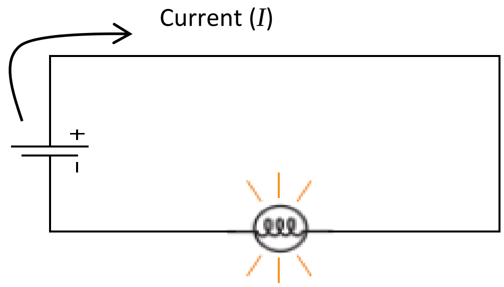
Q19. A wire of radius 1 mm and length 2 m is made of platinum (resistivity = 1×10^{-7} Ω•m). If a voltage of 9 V is applied between the ends of the wire, what will be the resulting current?

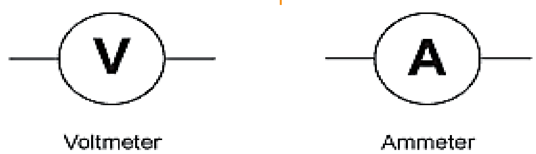
Q20. Considering Ohm's Law, make a sketch of the graphs for voltage vs. current and current vs. resistance. If either is nonlinear, how could you linearize the data? What would the slope of your linearized graph represent?

FACT: An electrical circuit is a closed loop path through which current can flow. The direction of current is the direction the *positive* charges flow. This unintuitive convention dates back to Ben Franklin, so remember on the AP Exam that the current is the direction of the *positive* charges from high to low, while the electrons flow in the opposite direction. Electrical circuits are typically represented in two dimensions using diagrams known as circuit schematics.

FACT: In the circuit below, the current (positive charge) flows from the positive terminal of the cell clockwise through a lamp to the negative terminal. The actual electrons in the wire, however, are flowing in the opposite direction, or counter-clockwise. I have also included some common circuit symbols below.







FACT: Let's derive an expression for electrical power. Electrical power is the rate at which electrical <u>energy is expended</u>. Recall that mechanical power is the rate at which work is done, P = $\frac{W}{t}$, and electrical work is the charge multiplied by the voltage, so P = $\frac{qV}{t}$. Now, recognize that $\frac{q}{t}$ is the current (I). Therefore, the electrical power expended in a circuit is the electrical current multiplied by potential difference (P = VI). Using Ohm's Law, you can expand this even further to provide several different methods for calculating electrical power dissipated by a resistor: P = VI = I^2R = $\frac{V^2}{R}$. On the AP Exam, remember that the brightness of a bulb depends solely on the power dissipated by the bulb.

Q21. (a). An electric iron operating at 120 volts draws 10 amperes of current. How much heat energy is delivered by the iron in 30 seconds? (b). Calculate the heat produced by an electric iron, which has a resistance of 30 ohms and takes a current of 3 amperes when it is switched on for 15 seconds.

Q22. A potential drop of 50 volts is measured across a 250-ohm resistor. What is the power developed in the resistor?

FACT: *Kirchhoff's junction rule* says that the sum of all current entering any point in a circuit has to equal the sum of all current leaving any point in a circuit. More simply, this is another way of looking at the law of conservation of charge. *Kirchhoff's loop rule* says that the sum of all the potential (voltage) drops in any closed loop of a circuit has to equal zero. More simply, it is a method of applying the law of conservation of energy to a circuit.

FACT: There are two basic circuit types in AP Physics and Kirchhoff's rules provide the tools to analyze any type of circuit. A series circuit is a circuit in which there is only a single current path. In a parallel circuit, there is more than one current path. Here are four key rules that you must use on a typical AP-style question regarding circuits:

1). *Series* resistors each carry the same current, which is equal to the total current through the series combination.

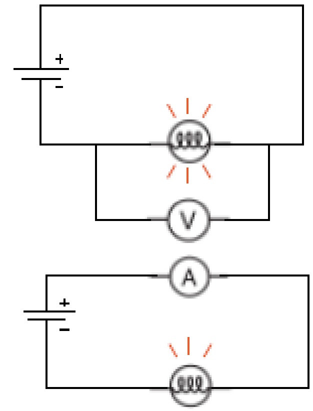
2). Voltage across *series* resistors is different for each but adds to the total voltage across the series combination.

3). Voltage across *parallel* resistors is the same for each and equal to the total voltage across the parallel combination.

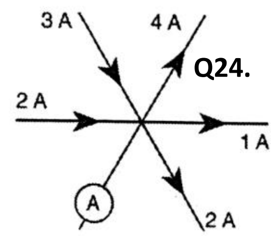
4). *Parallel* resistors each carry different current, which add to the total current through the parallel combination.

Q23. A 3.0-ohm resistor and a 6.0-ohm resistor are connected in series in an operating electric circuit. If the current through the 3.0-ohm resistor is 4.0 amperes, what is the potential difference across the 6.0-ohm resistor?

FACT: Voltmeters are tools used to measure the potential difference between two points in a circuit. The voltmeter is connected in parallel with the element to be measured; meaning an alternate current path around the element to be measured and through the voltmeter is created as shown to the right. Ammeters are tools used to measure the current in a circuit. The ammeter is connected in series with the circuit, so that the current to be measured flows directly through the ammeter. The circuit must be broken to correctly insert an ammeter. Ammeters have very low resistance to minimize the potential drop through the ammeter and the ammeter's impact on the circuit, so inserting an ammeter into a circuit in parallel can result in extremely high currents and may destroy the ammeter.

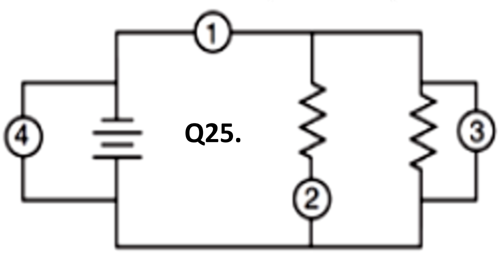


Q24. The diagram to the right represents currents in a segment of an electrical circuit. What is the reading on the ammeter?



Q25. In the electric circuit diagram below, possible locations of an ammeter and voltmeter are indicated by circles 1, 2, 3, and 4. Where should an ammeter be located to correctly measure the total current and where should a voltmeter be located to correctly measure the total voltage?

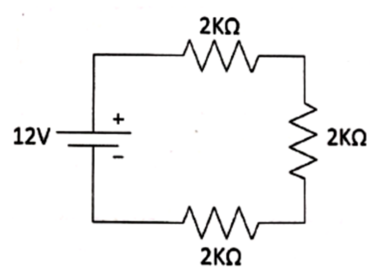
FACT: A simple and straightforward method for analyzing circuits involves creating a *VIRP* table for each circuit you encounter. A *VIRP* table describes the potential drop (V-voltage), current flow (I-current), resistance (R) and power dissipated (P-power) for each element in your circuit, as well as for the circuit as a whole. Even if a problem on the AP exam is asking a conceptual, qualitative question I recommend making a *VIRP* table, especially on an FRQ.



Q26. Create a VIRP table for the following series circuit.

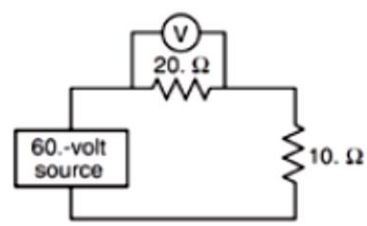
VIRP Table

	V	I	R	P
R_1				
R_2				
R_3				
Total				



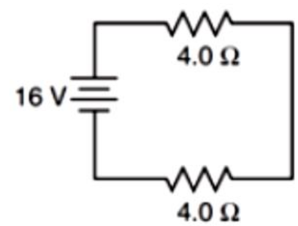
FACT: In *Q26*, there is only a single current path in the circuit, which travels through all three resistors. Instead of using three separate 2KΩ (2000Ω) resistors, you could replace the three resistors with one single resistor having an *equivalent resistance* (R_{eq}). To find the equivalent resistance of any number of *series* resistors, just add up the individual resistances: $R_{eq} = R_1 + R_2 + R_3$

Q27. In the circuit represented by the diagram on right, what is the reading of voltmeter V?

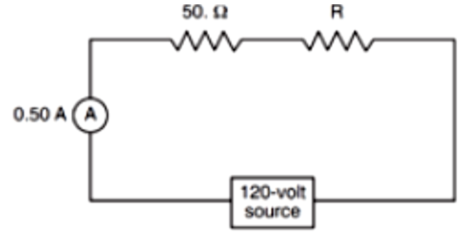


FACT: On the AP exam you may be asked about the usable energy, energy expended, or energy dissipation in a circuit. These types of questions require you to simply analyze the total power of the circuit. The greater the power, the greater the energy used in the circuit. Please reread the fact preceding Q21.

Q28. In the circuit diagram to the right, two 4.0-ohm resistors are connected to a 16-volt battery as shown. What is the rate at which electrical energy is expended in this circuit?

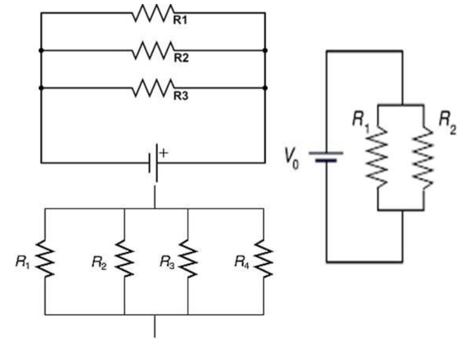


Q29. A 50-ohm resistor, an unknown resistor R, a 120-volt source, and an ammeter are connected in a complete circuit. The ammeter reads 0.50 ampere. (a). Calculate the equivalent resistance of the circuit. (b). Determine the resistance R (c). Calculate the power dissipated by resistor R.



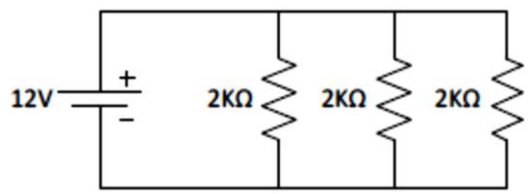
FACT: *River Analogy Revisited*- In parallel circuits, electricity can follow different paths through each of the resistors. In many ways, this is similar to a river branching into different smaller rivers. Each resistor, then, causes a potential drop (analogous to a waterfall), then the rivers recombine before heading back to the battery, which you can think of like a pump, raising the river to a higher potential before sending it back on its looping path. All three examples to the right show resistors in parallel.

Parallel circuits →



FACT: The equivalent resistance (R_{eq}) of parallel circuits is less than any individual resistor. For two identical resistors in parallel, their equivalent resistance is half of either resistor. If they are not identical use: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$. Also, note that the potential difference across each of the resistors in parallel is the same, and the current through each of the resistors adds up to the total current.

Q30. Complete a VIRP table for the following circuit on the right. →

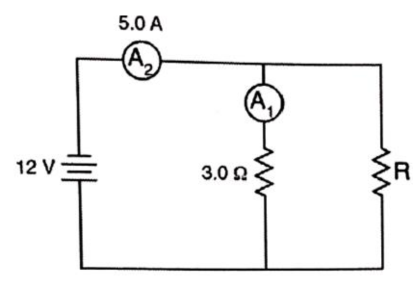


Q31. Draw a diagram of an operating circuit that includes: an ideal battery as a source of potential difference, two resistors in parallel with each other, and an ammeter that reads the total current in the circuit.

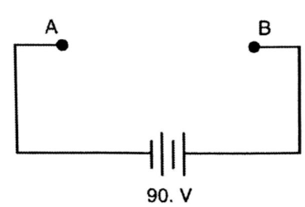
FACT: The electromotive force (emf, $\mathcal{E}$) typically means the source voltage of the circuit, while the term voltage, which can mean the emf, is more general and can be applied to the voltage drop between different points of the circuit. Real batteries also possess internal resistances (r). It is possible that College Board will ask a question about a battery with internal resistance or label the battery with the symbol $\mathcal{E}$. To find the terminal voltage of the battery with internal resistance simply subtract the voltage drop caused by the internal resistance: $V_{terminal} = \mathcal{E} - Ir$. An "ideal battery" has no internal resistance and, thus, the terminal voltage is equal to the emf of the battery.

Q32. Draw a diagram of an operating circuit that includes: A 12 V emf with 1.5 Ω of internal resistance and 2 A of current. The load on the circuit includes three identical lightbulbs. One bulb is in series and the remaining two are in parallel. Calculate the terminal voltage for the circuit and rank the bulbs based on their brightness.

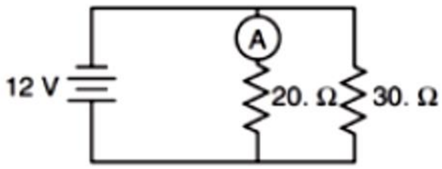
Q33. A 3-ohm resistor, an unknown resistor R, and two ammeters are connected as shown with a 12-volt source. Ammeter A_2 reads 5 amperes. (a). Find the R_{eq} of the circuit. (b). Find the current measured in A_1. (c). Calculate the resistance of the unknown resistor, R.



Q34. A 15-ohm resistor, R_1, and a 30-ohm resistor, R_2, are to be connected in parallel between points A and B. (a). Complete the diagram to show the two resistors connected in parallel. (b). Determine the potential difference across resistor R_1. (c). Calculate the current in R_1.

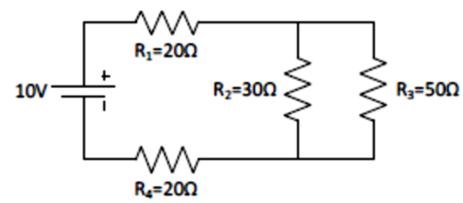


Q35. A 20-ohm resistor and a 30-ohm resistor are connected in parallel to a 12-volt battery as shown. An ammeter is connected as shown. (a) What is the equivalent resistance of the circuit? (b) What is the current reading of the ammeter? (c) What is the power of the 30-ohm resistor?

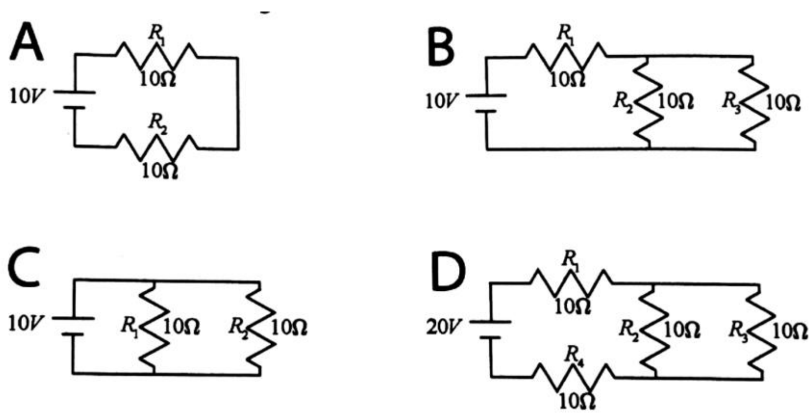


FACT: For combination series-parallel circuits replace the parallel resistors with an equivalent single resistor in series and draw a new schematic. Then you can analyze your equivalent series circuit with a VIRP table. Next, work back to your original circuit using Kirchoff's rules to determine the current, voltage, and resistance of each individual element in your circuit. College Board may use the term short circuit, which is simply a low resistance connection between the two conductors supplying electrical power to any circuit. This results in excessive current flow in the power source.

Q36. Find the current through R_2 in the circuit to the right.

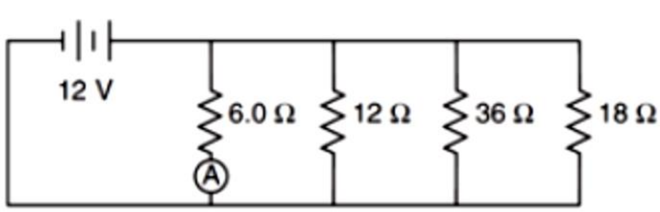


Q37. For each circuit below, rank the following quantities from highest to lowest if terms of: (a) Current through R_2; (b) Energy dissipated by R_1; (c) R_{eq} of entire circuit; (d) Potential drop across R_2. FIX B

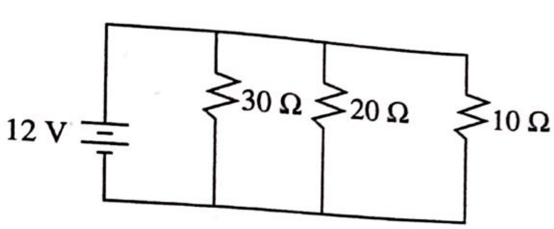


Instructions: For questions 38-45 complete VIRP tables for each circuit diagram.

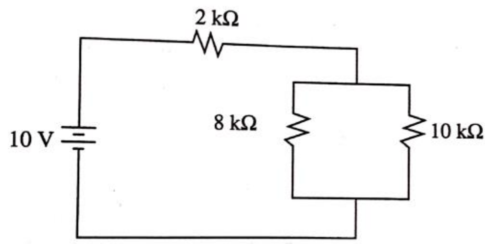
Q38.



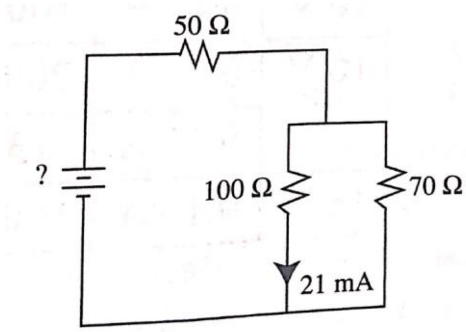
Q39.



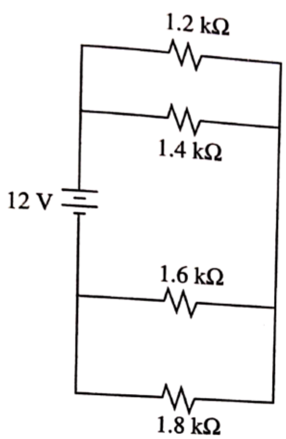
Q40.



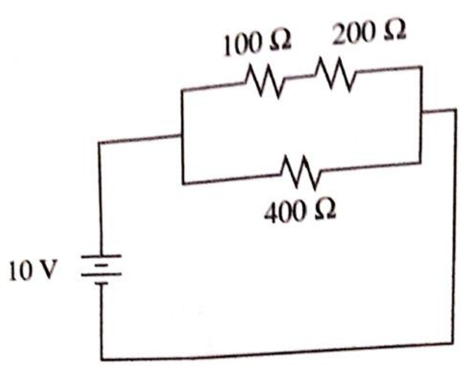
Q41.



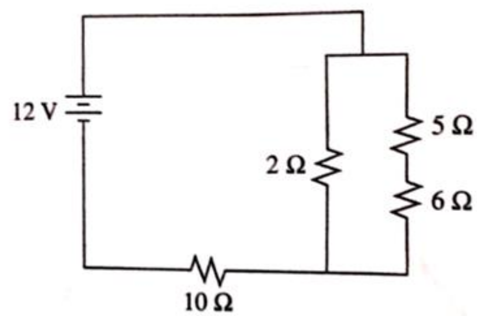
Q42.



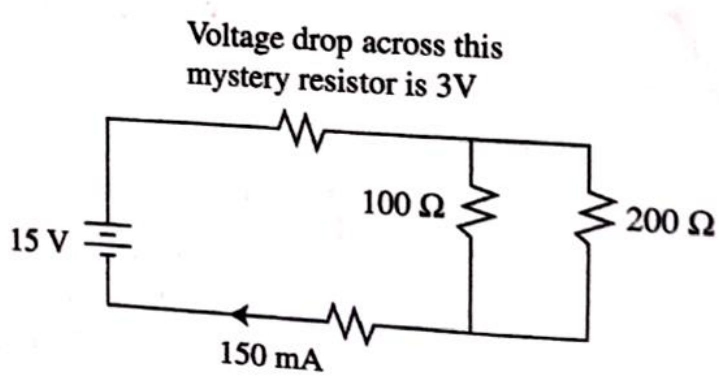
Q43.



Q44.



Q45.



[Solutions Video]