Question 21.1 Connect the Battery

Which is the correct way to light the lightbulb with the battery?

d) all are correct
e) none are correct

Current can flow only if there is a continuous connection from the negative terminal through the bulb to the positive terminal. This is the case for only Fig. (3).

Question 21.2 Ohm’s Law

You double the voltage across a certain conductor and you observe the current increases three times. What can you conclude?

a) Ohm’s law is obeyed since the current still increases when V increases
b) Ohm’s law is not obeyed
c) this has nothing to do with Ohm’s law

Ohm’s law, \( V = IR \), states that the relationship between voltage and current is linear. Thus, for a conductor that obeys Ohm’s law, the current must double when you double the voltage.

Follow-up: Where could this situation occur?

Question 21.3a Wires I

Two wires, \( A \) and \( B \), are made of the same metal and have equal length, but the resistance of wire \( A \) is four times the resistance of wire \( B \). How do their diameters compare?

a) \( d_a = 4d_b \)
b) \( d_a = 2d_b \)
c) \( d_a = d_b \)
d) \( d_a = 1/2d_b \)
e) \( d_a = 1/4d_b \)
### Question 21.3a Wires I

Two wires, \( A \) and \( B \), are made of the same metal and have equal length, but the resistance of wire \( A \) is four times the resistance of wire \( B \). How do their diameters compare?

- a) \( d_A = 4d_B \)
- b) \( d_A = 2d_B \)
- c) \( d_A = d_B \)
- d) \( d_A = 1/2d_B \)
- e) \( d_A = 1/4d_B \)

The resistance of wire \( A \) is greater because its area is less than wire \( B \). Since area is related to radius (or diameter) squared, the diameter of \( A \) must be two times less than the diameter of \( B \).

### Question 21.3b Wires II

A wire of resistance \( R \) is stretched uniformly (keeping its volume constant) until it is twice its original length. What happens to the resistance?

- a) it decreases by a factor of 4
- b) it decreases by a factor of 2
- c) it stays the same
- d) it increases by a factor of 2
- e) it increases by a factor of 4

Keeping the volume (= area x length) constant means that if the length is doubled, the area is halved. Since \( R = \frac{\rho L}{A} \) this increases the resistance by a factor of 4.

### Question 21.4a Series Resistors I

Assume that the voltage of the battery is 9 V and that the three resistors are identical. What is the potential difference across each resistor?

- a) 12 V
- b) zero
- c) 3 V
- d) 4 V
- e) you need to know the actual value of \( R \)

Since the resistors are all equal, the voltage will drop evenly across the 3 resistors, with 1/3 of 9 V across each one. So we get 3 V drop across each.

**Follow-up:** What would be the potential difference if \( R = 1 \Omega, 2 \Omega, 3 \Omega \)?

### Question 21.4b Series Resistors II

In the circuit below, what is the voltage across \( R_1 \)?

- a) 12 V
- b) zero
- c) 6 V
- d) 8 V
- e) 4 V

In the circuit below, what is the voltage across \( R_1 \)?

\( R_1 = 4 \Omega \quad R_2 = 2 \Omega \)
**Question 21.4b Series Resistors II**

In the circuit below, what is the voltage across \( R_1 \)?

- a) 12 V
- b) zero
- c) 6 V
- d) 8 V
- e) 4 V

The voltage drop across \( R_1 \) has to be twice as big as the drop across \( R_2 \). This means that \( \Delta V_1 = 8 \text{ V} \) and \( \Delta V_2 = 4 \text{ V} \). Or else you could find the current \( I = V/R = (12 \text{ V})/(6 \Omega) = 2 \text{ A} \), and then use Ohm’s law to get voltages.

Follow-up: What happens if the voltage is doubled?

**Question 21.5a Parallel Resistors I**

In the circuit below, what is the current through \( R_1 \)?

- a) 10 A
- b) zero
- c) 5 A
- d) 2 A
- e) 7 A

The voltage is the same (10 V) across each resistor because they are in parallel. Thus, we can use Ohm’s law, \( \Delta V = IR \), to find the current \( I = 2 \text{ A} \).

Follow-up: What is the total current through the battery?

**Question 21.5b Parallel Resistors II**

Points P and Q are connected to a battery of fixed voltage. As more resistors \( R \) are added to the parallel circuit, what happens to the total current in the circuit?

- a) increases
- b) remains the same
- c) decreases
- d) drops to zero

As we add parallel resistors, the overall resistance of the circuit drops. Since \( \Delta V = IR \), and \( \Delta V \) is held constant by the battery, when resistance decreases, the current must increase.

Follow-up: What happens to the current through each resistor?

**Question 21.6a Short Circuit I**

Current flows through a lightbulb. If a wire is now connected across the bulb, what happens?

- a) all the current continues to flow through the bulb
- b) half the current flows through the wire, the other half continues through the bulb
- c) all the current flows through the wire
- d) none of the above
**Question 21.6a** Short Circuit I
Current flows through a lightbulb. If a wire is now connected across the bulb, what happens?

- a) All the current continues to flow through the bulb
- b) Half the current flows through the wire, the other half continues through the bulb
- c) All the current flows through the wire
- d) None of the above

The current divides based on the ratio of the resistances. If one of the resistances is zero, then ALL of the current will flow through that path.

**Follow-up:** Doesn’t the wire have SOME resistance?

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**Question 21.6b** Short Circuit II
Two lightbulbs A and B are connected in series to a constant voltage source. When a wire is connected across B, bulb A will:

- a) Glow brighter than before
- b) Glow just the same as before
- c) Glow dimmer than before
- d) Go out completely
- e) Explode

Since bulb B is bypassed by the wire, the total resistance of the circuit decreases. This means that the current through bulb A increases.

**Follow-up:** What happens to bulb B?

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**Question 21.7a** Circuits I
The lightbulbs in the circuits below are identical with the same resistance \( R \). Which circuit produces more light? (brightness \( \propto \) power)

- a) Circuit I
- b) Circuit II
- c) Both the same
- d) It depends on \( R \)

In circuit I, the bulbs are in parallel, lowering the total resistance of the circuit. Thus, circuit I will draw a higher current, which leads to more light, because \( P = IV \).

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**Question 21.7b** Circuits II
The three lightbulbs in the circuit all have the same resistance of 1 Ω. By how much is the brightness of bulb B greater or smaller than the brightness of bulb A? (brightness \( \propto \) power)

- a) Twice as much
- b) The same
- c) 1/2 as much
- d) 1/4 as much
- e) 4 times as much

The three lightbulbs in the circuit all have the same resistance of 1 Ω. By how much is the brightness of bulb B greater or smaller than the brightness of bulb A? (brightness \( \propto \) power)
**Question 21.7b** Circuits II

The three lightbulbs in the circuit all have the same resistance of 1 Ω. By how much is the brightness of bulb B greater or smaller than the brightness of bulb A? (brightness \( \propto \) power)

- a) twice as much
- b) the same
- c) 1/2 as much
- d) 1/4 as much
- e) 4 times as much

We can use \( P = \frac{V^2}{R} \) to compare the power:

\[
P_A = \frac{(\Delta V_A)^2}{R_A} = \frac{(10 \text{ V})^2}{1 \Omega} = 100 \text{ W}
\]

\[
P_B = \frac{(\Delta V_B)^2}{R_B} = \frac{(5 \text{ V})^2}{1 \Omega} = 25 \text{ W}
\]

**Follow-up:** What is the total current in the circuit?

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**Question 21.8a** More Circuits I

What happens to the voltage across the resistor \( R_1 \) when the switch is closed? The voltage will:

- a) increase
- b) decrease
- c) stay the same

With the switch closed, the addition of \( R_2 \) to \( R_3 \) decreases the equivalent resistance so the current from the battery increases. This will cause an increase in the voltage across \( R_1 \).

**Follow-up:** What happens to the current through \( R_2 \)?

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**Question 21.8b** More Circuits II

What happens to the voltage across the resistor \( R_2 \) when the switch is closed?

- a) increases
- b) decreases
- c) stays the same

We just saw that closing the switch causes an increase in the voltage across \( R_1 \) (which is \( V_{ab} \)). The voltage of the battery is constant so if \( V_{ab} \) increases then \( V_{bc} \) must decrease.

**Follow-up:** What happens to the current through \( R_2 \)?

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**Question 21.9** Even More Circuits

Which resistor has the greatest current going through it? Assume that all the resistors are equal.

- a) \( R_1 \)
- b) both \( R_1 \) and \( R_3 \) equally
- c) \( R_2 \) and \( R_4 \)
- d) \( R_3 \)
- e) all the same
The same current must flow through left and right combinations of resistors. On the LEFT, the current splits equally, so \( I_1 = I_2 \). On the RIGHT, more current will go through \( R_5 \) than \( R_3 + R_4 \) since the branch containing \( R_5 \) has less resistance.

**Question 21.9**

Which resistor has the greatest current going through it? Assume that all the resistors are equal.

- a) \( R_1 \)
- b) both \( R_1 \) and \( R_2 \) equally
- c) \( R_2 \) and \( R_4 \)
- d) \( R_5 \)
- e) all the same

**Follow-up:** Which one has the smallest voltage drop?

**Question 21.10**

When you rotate the knob of a light dimmer, what is being changed in the electric circuit?

- a) the power
- b) the current
- c) the voltage
- d) both a) and b)
- e) both b) and c)

**Follow-up:** Why does the voltage not change?

**Question 21.11a**

Two lightbulbs operate at 120 V, but one has a power rating of 25 W while the other has a power rating of 100 W. Which one has the greater resistance?

- a) the 25 W bulb
- b) the 100 W bulb
- c) both have the same
- d) this has nothing to do with resistance

**Follow-up:** Which one carries the greater current?

Since \( P = \frac{V^2}{R} \), the bulb with the lower power rating has to have the higher resistance.

**Question 21.11b**

Two space heaters in your living room are operated at 120 V. Heater 1 has twice the resistance of heater 2. Which one will give off more heat?

- a) heater 1
- b) heater 2
- c) both equally

**Follow-up:** Which one carries the greater current?
Using \( P = \frac{V^2}{R} \), the heater with the smaller resistance will have the larger power output. Thus, heater 2 will give off more heat.

**Follow-up:** Which one carries the greater current?

**Question 21.12**

**Junction Rule**

What is the current in branch P?

- a) 2 A
- b) 3 A
- c) 5 A
- d) 6 A
- e) 10 A

The current entering the junction in red is 8 A, so the current leaving must also be 8 A. One exiting branch has 2 A, so the other branch (at P) must have 6 A.

**Question 21.13**

**Kirchhoff's Rules**

The lightbulbs in the circuit are identical. When the switch is closed, what happens?

- a) both bulbs go out
- b) intensity of both bulbs increases
- c) intensity of both bulbs decreases
- d) A gets brighter and B gets dimmer
- e) nothing changes

When the switch is open, the point between the bulbs is at 12 V. But so is the point between the batteries. If there is no potential difference, then no current will flow once the switch is closed!! Thus, nothing changes.

**Follow-up:** What happens if the bottom battery is replaced by a 24 V battery?

**Question 21.14**

**Wheatstone Bridge**

An ammeter A is connected between points a and b in the circuit below, in which the four resistors are identical. The current through the ammeter is:

- a) I
- b) I/2
- c) I/3
- d) I/4
- e) zero
**Question 21.14** Wheatstone Bridge

An ammeter A is connected between points a and b in the circuit below, in which the four resistors are identical. The current through the ammeter is:

- a) \( I \)
- b) \( I/2 \)
- c) \( I/3 \)
- d) \( I/4 \)
- e) zero.

Since all resistors are identical the voltage drops are the same across the upper branch and the lower branch. Thus, the potentials at points a and b are also the same. Therefore, no current flows.

**Question 21.15** More Kirchhoff’s Rules

Which of the equations is valid for the circuit below?

- a) \( 2 - I_1 - 2I_2 = 0 \)
- b) \( 2 - 2I_1 - 2I_2 - 4I_3 = 0 \)
- c) \( 2 - I_1 - 4 - 2I_2 = 0 \)
- d) \( I_1 - 4 - 2I_2 + 6 = 0 \)
- e) \( 2 - I_1 - 3I_2 - 6 = 0 \)

Eqn. 3 is valid for the left loop. The left battery gives +2V, then there is a drop through a 1Ω resistor with current \( I_1 \) flowing. Then we go through the middle battery (but from + to −), which gives −4V. Finally, there is a drop through a 2Ω resistor with current \( I_2 \).

**Question 21.16a** Capacitors I

What is the equivalent capacitance, \( C_{eq} \), of the combination below?

- a) \( C_{eq} = \frac{3}{2}C \)
- b) \( C_{eq} = \frac{3}{4}C \)
- c) \( C_{eq} = 3C \)
- d) \( C_{eq} = \frac{1}{3}C \)
- e) \( C_{eq} = \frac{1}{2}C \)

The 2 equal capacitors in series add up as inverses, giving \( \frac{1}{2}C \). These are parallel to the first one, which add up directly. Thus, the total equivalent capacitance is \( \frac{3}{2}C \).

**Question 21.16b** Capacitors II

How does the voltage \( V_i \) across the first capacitor \( (C_i) \) compare to the voltage \( V_j \) across the second capacitor \( (C_j) \)?

- a) \( V_1 = V_2 \)
- b) \( V_1 > V_2 \)
- c) \( V_1 < V_2 \)
- d) all voltages are zero
**Question 21.16b** Capacitors II

How does the voltage $V_1$ across the first capacitor ($C_1$) compare to the voltage $V_2$ across the second capacitor ($C_2$)?

- **a)** $V_1 = V_2$
- **b)** $V_1 > V_2$
- **c)** $V_1 < V_2$
- **d)** all voltages are zero

Follow-up: What is the current in this circuit?

The voltage across $C_1$ is 10 V. The combined capacitors $C_2 + C_3$ are parallel to $C_1$. The voltage across $C_2 + C_3$ is also 10 V. Since $C_2$ and $C_3$ are in series, their voltages add. Thus the voltage across $C_2$ and $C_3$ each has to be 5 V, which is less than $V_1$.

**Question 21.16c** Capacitors III

How does the charge $Q_1$ on the first capacitor ($C_1$) compare to the charge $Q_2$ on the second capacitor ($C_2$)?

- **a)** $Q_1 = Q_2$
- **b)** $Q_1 > Q_2$
- **c)** $Q_1 < Q_2$
- **d)** all charges are zero

We already know that the voltage across $C_1$ is 10 V and the voltage across both $C_2$ and $C_3$ is 5 V each. Since $Q = CV$ and $C$ is the same for all the capacitors, we have $V_1 > V_2$ and therefore $Q_1 > Q_2$. 

Follow-up: What is the current in this circuit?