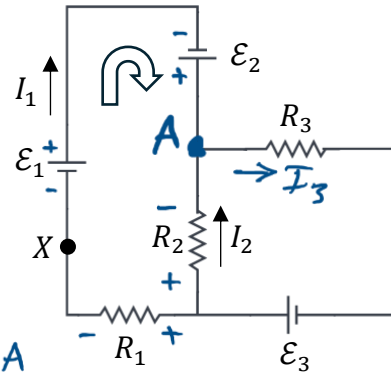


Multiple Choice [5 pts each] Bubble in the most correct answer on your bubble sheet and circle the correct answer here.

Use the circuit at right to answer the next two questions.

1. [5 pts] In the circuit shown, if $I_1 = 3.2 \text{ A}$ and $I_2 = 1.7 \text{ A}$, what is the current flowing through the resistor R_3 and in what direction?



69%

- A. 3.2 A to the left.
 B. 4.9 A to the right.
 C. 1.5 A to the right.
 D. 1.7 A to the left.
 E. 2.5 A to the right.

At junction A:
 $\sum I_{in} = \sum I_{out}$
 $I_1 + I_2 = I_3$
 $\Rightarrow I_3 = 3.2 \text{ A} + 1.7 \text{ A}$
 $\Rightarrow I_3 = 4.9 \text{ A}$

2. [5 pts] Consider the left loop designated by the thick arrow. Which one of the following represents correct application of Kirchhoff's loop equation to that loop starting and ending at point X?

45%

- A. $-\mathcal{E}_1 - \mathcal{E}_2 + I_2 R_2 + I_1 R_1 = 0$
 B. $+\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_2 - I_1 R_1 = 0$
 C. $+\mathcal{E}_1 + \mathcal{E}_2 + I_2 R_2 - I_1 R_1 = 0$
 D. $+\mathcal{E}_1 - \mathcal{E}_2 + I_2 R_2 - I_1 R_1 = 0$
 E. $+\mathcal{E}_1 + \mathcal{E}_2 - I_2 R_2 - I_1 R_1 = 0$

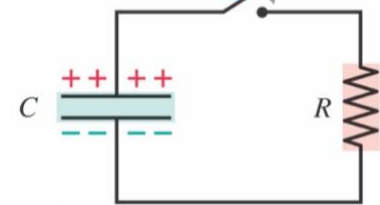
$\Delta V_{XX} = 0$
 $\Rightarrow +\mathcal{E}_1 + \mathcal{E}_2 + I_2 R_2 - I_1 R_1 = 0$

Use the circuit at right to answer the next two questions

The circuit at right has a charged capacitor of capacitance C connected to a resistor of resistance R .

3. [5 pts] When the switch is closed, we measure the potential difference across the capacitor ΔV_C as a function of time.

The switch will close at $t = 0$.



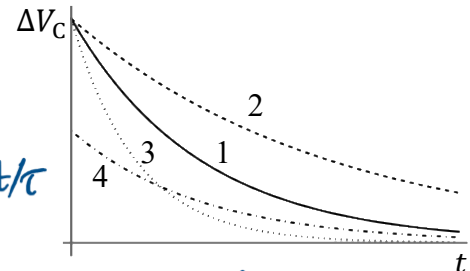
The solid curve in the graphic at right to the bottom is obtained, labeled "1".

56%

If we now repeat this experiment by recharging the capacitor to the same initial potential difference but use a smaller resistance than R , which curve would we get for the new ΔV_C ?

Hint: $\tau = RC$

- A. Curve 1 (solid), no change.
 B. Curve 2 (dashed)
 C. Curve 3 (dotted)
 D. Curve 4 (dot-dashed)



$\Delta V_C = (\Delta V_C)_0 e^{-t/\tau}$
 $(\Delta V_C)_0$ stays same \Rightarrow not curve 4
 R decreases $\Rightarrow \tau$ decreases
 \Rightarrow it takes less for ΔV_C to drop
 \Rightarrow must be curve 3

First

Last

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4. [5 pts] Now assume $R = 7.00 \times 10^6 \Omega$ and $C = 3.00 \times 10^{-7} \text{ F}$. At the moment the switch is closed, the potential difference across the capacitor ΔV_C is 5.00 V. What is the value of ΔV_C after 3.00 s from closing the switch?

70%

- A. 3.80 V
- B. 1.20 V**
- C. 4.30 V
- D. 0.71 V
- E. 2.50 V

$$\Delta V_c = (\Delta V_c)_0 e^{-t/\tau}$$

$$= (5.00 \text{ V}) \left(e^{-\frac{3.00 \text{ s}}{7.00 \times 10^6 \Omega \cdot 3.00 \times 10^{-7} \text{ F}}} \right)$$

$$= 1.2 \text{ V}$$

5. [5 pts] A solenoid with 8500 turns is 1.2 m long and has a radius of 9.5 cm. If the magnetic field inside the solenoid is 2.3 T, then what is the current through the solenoid?

86%

- A. 0.020 A
- B. 2.76 A
- C. 215 A
- D. 260 A**
- E. 2000 A

$$B_{\text{solenoid}} = \frac{\mu_0 N I}{L} \Rightarrow I = \frac{L B_{\text{solenoid}}}{\mu_0 N}$$

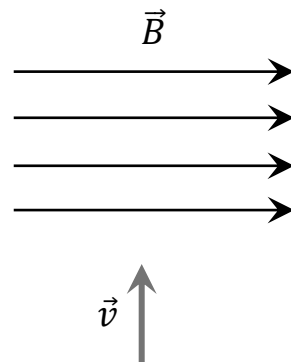
$$= \frac{(1.2 \text{ m})(2.3 \text{ T})}{(1.26 \times 10^{-6} \frac{\text{Tm}}{\text{A}})(8500 \text{ turns})} = 260 \text{ A}$$

6. [5 pts] A point charge with positive charge $+q$ traveling upward with velocity \vec{v} enters a region with uniform magnetic field \vec{B} directed to the right as shown. When the point charge enters this region, what is the direction of the magnetic force?

82%

- A. To the right
- B. To the left
- C. Upward
- D. Out of the page
- E. Into the page**

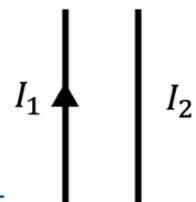
use 2nd RHR



7. [5 pts] Two long straight wires are oriented as shown, and nothing else is nearby. The current in the left wire is I_1 and is directed upward. The current in the right wire is I_2 , but the direction of the current is not known. If you observe an **attractive** magnetic force between the wires, then which of the following must be true about the current I_2 ?

63%

- A. The current I_2 is upward**
- B. The current I_2 is downward
- C. $I_2 = 0$
- D. Magnetic fields never exert forces on wires.
- E. There is not enough information to answer.



Field due to I_1 at location of I_2 using 1st RHR is into page.

Now using 2nd RHR: force on I_2 is to left $\Rightarrow I_2$ must be upward

8. [5 pts] A given sandwich has 35 g of carbohydrates, 12 g of protein and 15 g of fat. Using the table at right, calculate the energy content of the sandwich in Calories.

Fuel (in food)	Energy in 1 g of fuel (in kJ)
Fat	38
Carbohydrates	17
Protein	17

86%

- A. 215 Cal
 B. 280 Cal
 C. 327 Cal
 D. 410 Cal
 E. 1370 Cal

$$E_{tot} = E_{carb} + E_{prot} + E_{fat}$$

$$= \left(35g \times \frac{17kJ}{1g}\right) + \left(12g \times \frac{17kJ}{1g}\right) + \left(15g \times \frac{38kJ}{1g}\right)$$

$$= 595kJ + 204kJ + 570kJ = 1370kJ$$

$$= 1370 \times 10^3 J \times \frac{1 Cal}{4190J} = 327 Cal$$

9. [5 pts] Two samples of ideal gas, sample 1 and sample 2, have the same thermal energy. Sample 1 has twice as many atoms as sample 2. Is the temperature of sample 1 *greater than*, *less than* or *equal to* the temperature of sample 2?

72%

- A. Greater than
 B. Less than
 C. Equal to
 D. Information provided is not enough to answer.

$$E_{th,1} = E_{th,2}$$

$$E_{th} \propto T \text{ and } E_{th} \propto N ; N_1 > N_2$$

$$\Rightarrow T_1 < T_2$$

10. [5 pts] Engine A has a 29.0% efficiency, while the efficiency of Engine B is 34.0%. If Engine A needs 30.0 kW of fuel power to achieve its task, how much power would it require Engine B to achieve the same task?

68%

- A. 25.6 kW
 B. 35.1 kW
 C. 8.70 kW
 D. 10.20 kW
 E. 18.3 kW

We need $power_B$; get $A = get_B$ and $e = \frac{get}{ray}$

$$\Rightarrow get = e \cdot ray \Rightarrow e_A power_A = e_B power_B$$

$$\Rightarrow power_B = \frac{e_A}{e_B} power_A = \frac{0.29}{0.34} \cdot 30.0kW = 25.6kW$$

11. [5 pts] A system is acted on by its surroundings in such a way that it receives 50 J of heat while simultaneously doing 20 J of work on the surrounding environment. What is its net change in internal (thermal) energy?

86%

- A. -70 J
 B. 70 J
 C. 30 J
 D. Zero
 E. -30 J

$$\Delta E_{th} = W_{on} + Q = -W_{by} + Q$$

$$= -20J + 50J = 30J$$

12. [5 pts] Consider a system whose entropy is decreasing during a certain time interval. According to the second law of thermodynamics:

- A. this process is impossible, as the second law prohibits entropy from decreasing.
- B. the entropy change of the surroundings must be at least as large and opposite in sign, so that the total entropy change of the system plus surroundings is non-negative.
- C. the entropy of a system fluctuates all the time, so that it would increase back again.
- D. this could happen only if the system is isolated in order not to affect the increase of entropy of the entire universe.
- E. this could not happen, because no system can be isolated from the rest of the universe.

75%

- A. System's entropy can decrease; total entropy cannot
- B. The entropy of the system and surrounding cannot decrease
- C. The 2nd law concerns isolated systems over time and does not say anything about entropy fluctuation
- D. Entropy of an isolated system does not decrease.
- E. This statement is talking about isolated system but the problem concerns a decrease in entropy which could happen if the system is not isolated.

Lecture Free Response [20 pts total]: Show work and/or explain reasoning where indicated.

A rock climber of mass 68 kg wants to climb a hill of height 200 m. During the climb this person is able to maintain a metabolic power of 300 W while climbing vertically at a speed of 0.15 m/s. Right before the climb, they ate a snack that has 80 Calories. Assume that snack to be the only source of energy during the climb. Do not assume a 25% efficiency.

13. [3 pts] How long would it take the climber to reach the top in minutes?

$$v = \frac{\Delta y}{\Delta t} \Rightarrow \Delta t = \frac{\Delta y}{v} = \frac{200 \text{ m}}{0.15 \text{ m/s}} = 1333 \text{ s} = 1333 \text{ s} \times \frac{1 \text{ min}}{60 \text{ s}} = \boxed{22.2 \text{ min}}$$

83%

1 pt Equation – The equation $v = \Delta y / \Delta t$ is used

1 pt Unit conversion – Student converts units of seconds to minutes

1 pt Final answer – Student gets the correct final answer ~22.2 minutes

0 Wrong/blank

14. [7 pts] Find how much energy in Calorie would that climber consume during the climb. Is the energy supplied by the snack *greater than*, *less than* or *equal to* the energy required by the climb? Explain briefly.

66%

$$\Delta E_{\text{chem}} = P_{\text{metabolic}} \cdot \Delta t$$

$$\Rightarrow \Delta E_{\text{chem}} = (300 \text{ W})(1333 \text{ s}) = 4.0 \times 10^5 \text{ J}$$

We now convert to Cal:

$$\Delta E_{\text{chem}} = 4.0 \times 10^5 \text{ J} \times \frac{1 \text{ Cal}}{4190 \text{ J}} = \boxed{95.5 \text{ Cal}}$$

Comparing this number with the energy provided by the snack of 80 Cal, we see that:

$$\Delta E_{\text{chem}} > E_{\text{snack}}$$

Therefore, the climber needs to consume about 96 Cal, which is more than the amount provided by the snack, so that the energy provided by the snack is less than the energy required by the climb.

1.5 pts Energy for climb – Student uses $\Delta E_{\text{chem}} = P_{\text{metabolic}} \cdot \Delta t$ to calculate the energy required for the climb.

1.5 pt Energy for climb – Student shows work for the provided calculation

–0.5 pt Energy for climb – Student does not include units in the provided calculations

2.0 pts Unit conversion – Student converts from Joules (J) to Calories (Cal) showing all work, including units in all calculations

–0.5 pt Unit conversion – Student does not include units in the provided calculations

–1.0 pt Unit conversion – Student does not show work for unit conversion calculation

1 pt Calorie comparison – Student compares energy from the snack to that required for the climb AND the answer is consistent with previous calculations

(The expected answer is *LESS THAN* but the comparison needs to simply be consistent with the provided work.)

1 pt Correct final answer – LESS THAN

0 pt Incorrect/blank

15. [5 pts] Calculate the mechanical power. *Hint: $P = W/t = Fv$.*
 The mechanical power is the power associated with the actual task of climbing. The climber is going up at constant speed, which means they exert a force equal to their weight:

69%

$$P = F \cdot v$$

$$F = mg = (68 \text{ kg})(9.8 \text{ m/s}^2) = 666.4 \text{ N}$$

$$v = 0.15 \text{ m/s}$$

$$\Rightarrow P = F \cdot v = (666.4 \text{ N})(0.15 \text{ m/s}) = 99.9 \text{ W} \approx \boxed{100 \text{ W}}$$

- 2 pts Correct final answer – Mechanical power $\approx 100 \text{ W}$
 1.5 pts Calculation – Student uses either $P = W/t$ or $P = F \cdot v$
 1.5 pts Calculation – Student shows all work, including units for all calculations
 –0.5 pt Calculation – Student does not include units in the provided calculation
 0 Incorrect/blank

16. [5 pts] Use your answer above to calculate the climber's efficiency.
 If you couldn't answer the previous question assume $P = 90 \text{ W}$.

71%

$$e = \frac{\text{what you get}}{\text{what you pay}} = \frac{\text{power out}}{\text{power in}}$$

$$\text{power out} = 100 \text{ W}, \quad \text{power in} = 300 \text{ W}$$

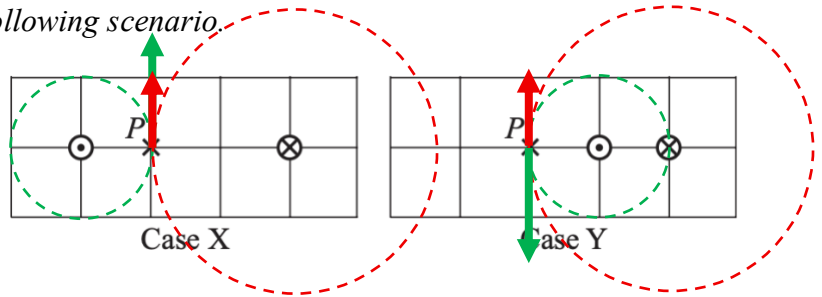
$$\Rightarrow e = \frac{100 \text{ W}}{300 \text{ W}} = 0.33 = \boxed{33\%}$$

- If student uses $P = 90 \text{ W} \Rightarrow e = 90 \text{ W}/300 \text{ W} = 0.30 = 30\%$
 2 pts Equation – Student explicitly states and uses the efficiency equation $e = \frac{\text{power out}}{\text{power in}}$
 or $e = \frac{\text{what you get}}{\text{what you pay}}$
 1 pt Calculation – Student accurately identifies the **POWER OUT/WHAT YOU GET** to be 100 W from previous part OR uses the provided 90 W
 1 pt Calculation – Student accurately identifies the **POWER IN/WHAT YOU PAY** to be 300 W
 1 Final answer consistent
 –0.5 Calculation – Student does not include units in provided calculations
 0 Incorrect/blank

Tutorial Free Response [20 pts total]: Problems 17-20. Show work and/or explain reasoning where indicated.

The next two questions are related to the following scenario.

In each case at right, two infinite parallel wires carry equal, constant currents I . (\otimes and \odot indicates current into and out of the page, respectively.)



17. [5 pts] In each case, a compass is placed at point P . On each diagram, indicate the direction in which the north pole of the compass needle will point. No explanation needed.

Case X:

2.5 pt Arrow points upward

1 pt partial credit – Arrow points downward (*in the opposite direction to the correct answer*).

Case Y:

2.5 pt Arrow points downward

1 pt partial credit – Arrow points upward (*in the opposite direction to the correct answer*).

0 Incorrect/Blank

52%

18. [5 pts] Is the magnitude of the magnetic field at point P in case X *greater than*, *less than*, or *equal to* that in case Y ? **Explain.**

2 pts Correct answer – Case X is *GREATER THAN* Case Y

1.5 pts Distance comparison – Student compares distance from each wire to point P

1.5 pts Superposition – Student attempts to use the superposition principle

–0.5 pt Incorrect distance comparison (must compare distance of wires between cases)

0 Incorrect/blank

51%

In the next two questions, assume all bulbs are identical and all batteries are identical and ideal.

19. [5 pts] Two circuits are shown at right. Is bulb A *brighter than*, *dimmer than*, or *as bright as* bulb B ? **Explain your reasoning.**

2.5 pts Correct answer – Bulb A is *DIMMER THAN* bulb B

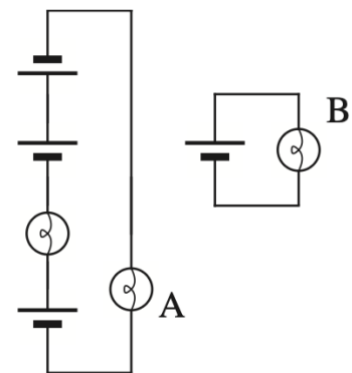
Explanation:

2.5 Qualitative answer/loop rule—Student makes a qualitative argument (e.g., "left circuit is like a 1 battery 2 bulb series circuit") OR the loop rule is used for both circuits

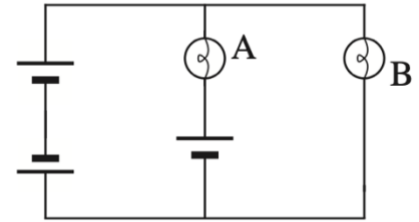
1 pt Partial credit—Student makes an incorrect, but reasonable, attempt at using the loop rule

0 Incorrect/blank

61%



20. [5 pts] The circuit elements are rearranged to form the circuit at right. In this new circuit, does bulb B light up? **Explain your answer using the loop rule.**



34%

2 pts Correct answer—Bulb B *DOES NOT* light up

1 pt Equation – Student finds/states that $\Delta V_B = 0$

Explanation:

2 pts Calculation/explanation—Student applies Kirchhoff's

Law to the outer loop (*this includes the two batteries in opposite directions which "cancel"—total voltage across them together is zero—and the bulb B*)

1 pt Partial credit—The loop rule is used, with some mistakes, which results in an incorrect final answer

0 Incorrect/blank