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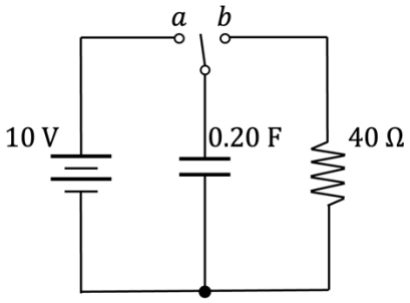
I. [60 pts] Multiple Choice: Mark your answer on BOTH the bubble sheet and this page.

1. [5 pts] The 0.20 F capacitor in the circuit at right is initially uncharged and the switch is open. First, the switch is flipped to position ***a*** and left there for a long time, allowing the capacitor to fully charge. We then flip the switch to position ***b***. What is the current through the 40 Ω resistor, exactly 6.0 s after the switch is flipped to position ***b***?



   A. 0

   B. 0.12 A

   C. 0.36 A

   D. 4.3 A

   E. 26 A

2. [5 pts] The diagrams at right show four depictions of a magnetic field. Which of the field diagrams is most correct?

   A. I only

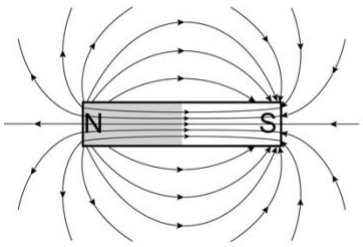
   B. II only

   C. III only

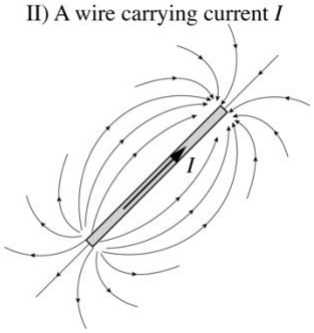
   D. IV only

   E. None is correct

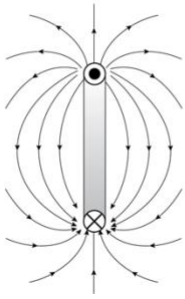
I) A bar magnet



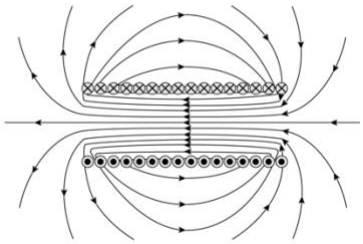
II) A wire carrying current *I*



III) A single current loop



IV) A solenoid



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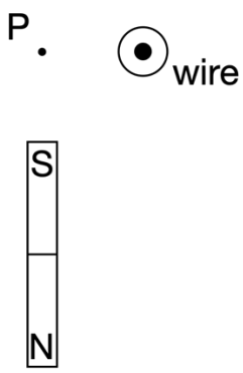
3. [5 pts] A long straight wire with a current out of the page is next to a bar magnet. Point P is directly to the left of the wire and directly above the bar magnet. The magnitudes of the magnetic fields from the wire and the magnet are the same at point P. What is the direction of the magnetic field at point P?



A. ↓

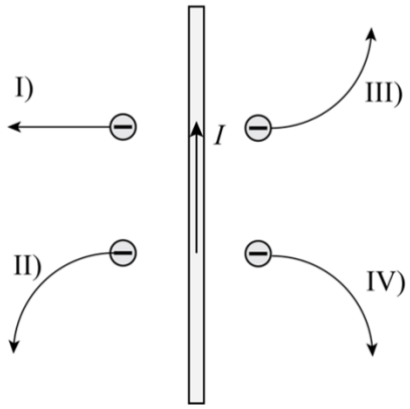
B. ↑

C. ↖

D. ↘

E. The magnetic field has zero magnitude at point P, and therefore, no direction.

4. [5 pts] A wire is carrying a positive current *I* as shown in the diagram at right. A negatively charged particle is moving in the magnetic field generated by the current in the wire. Which of the trajectories (I – IV) are possible?



A. I only

B. II and IV

C. II and III

D. III and IV

E. None is correct

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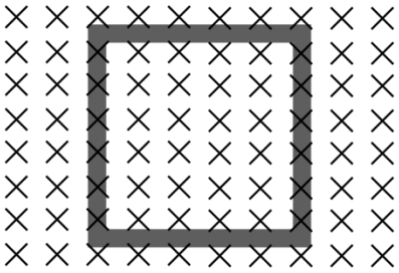
5. [5 pts] What is the magnitude of the total force on a square loop with width L that carries a clockwise current I in a uniform magnetic field B, in a configuration shown in the figure?



   A. $4ILB$

   B. $2ILB$

   C. ILB

   D. 0

   E. Not enough information is given

6. [5 pts] When running a full marathon race of 42.1 km, an elite runner has an average total metabolic power measured at 400 Watts. If the runner finishes the race with an average speed of 17.7 km per hour, how many Calories did the runner burn over the entire race?

   A. 3.40×10^6 Calories

   B. 14.0 Calories

   C. 1320 Calories

   D. 953 Calories

   E. 818 Calories

7. [5 pts] The Global Seed Vault in Svalbard, located in the Arctic, safeguards over one million seed samples from the world's crop collections as a precaution against catastrophic losses. The vault is kept at −18.0°C to ensure optimal seed preservation. If American scientists were to communicate this temperature in Fahrenheit, what value would they report?

   A. -64.4 °F

   B. -27.8 °F

   C. -0.400 °F

   D. 7.80 °F

   E. 25.2 °F

8. [5 pts] A crane at a construction site uses an electric motor with 40% efficiency to lift things. How much electric energy in kWh does the crane use to lift a bundle of steel bars with a mass of 2000 kg from the ground level to a height of 10 meters? (Note: Utility company bills for electricity energy in unit of kWh, 1 kWh=1000 watts × 1 hour).

   A. 5×10^4 kWh

   B. 500 kWh

   C. 8.3 kWh

   D. 0.02 kWh

   E. 0.14 kWh

9. [5 pts] A sealed container of boiling water is dropped in the ocean. We wait for some time for the temperatures to equilibrate. Determine whether the entropy change of the container (including the water in it) $\Delta S_{container}$, the entropy change of the ocean (including the air around it) ΔS_{ocean}, and the entropy change of the combined system $\Delta S_{container+ocean}$ increases (> 0), decreases (< 0), stays the same (= 0), or whether there is not enough information given to know.

   A. $\Delta S_{container} < 0$, $\Delta S_{ocean} > 0$, $\Delta S_{container+ocean} = 0$

   B. $\Delta S_{container} > 0$, $\Delta S_{ocean} < 0$, $\Delta S_{container+ocean} = 0$

   C. $\Delta S_{container} < 0$, $\Delta S_{ocean} > 0$, $\Delta S_{container+ocean} > 0$

   D. $\Delta S_{container} > 0$, $\Delta S_{ocean} = 0$, $\Delta S_{container+ocean} > 0$

   E. Not enough information is given.

10. [5 pts] A bottle contains 1 m^3 of pure nitrogen gas (formula: N_2) with a pressure of 2.0×10^5 Pascal and at temperature of 17 ºC. The atomic mass number of nitrogen is 14.

    What is the mass of N_2 gas in the bottle?

    A. 3.86×10^{-27} kg

    B. 6.58×10^{-26} kg

    C. 2.32 kg

    D. 38.6 kg

    E. 4.73×10^{3} kg

11. [5 pts] Two containers, A and B, are each filled with a different monatomic noble gas in thermal equilibrium: container A holds helium gas, and container B holds neon gas. The total thermal energies of the two gases are equal, and the helium and neon atoms have the same root-mean-square (rms) speed. What is the ratio of the number of moles of helium in container A to the number of moles of neon in container B, $\frac{n_A}{n_B}$?

    The atomic mass of Helium is 4 u, and the atomic mass of Neon is 20 u.

    A. 5

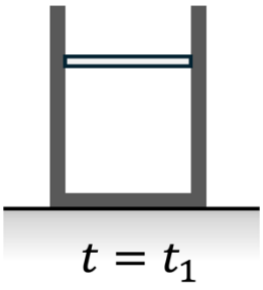
    B. 1/5

    C. 25

    D. 1/25

    E. Not enough information is given

12. [5 pts] At $t = t_0$, a container seals a volume of ideal gas with a movable frictionless piston on the top. The piston is at rest and the gas pressure is p_0. At $t = t_1$, the container is placed above a flame and warmed slowly. Which of the following statements is FALSE?



    A. The internal energy of the gas in the container increases.

    B. The pressure of the gas in the container increases.

    C. The heat flow into the gas in the container is positive.

    D. The volume of the gas in the container increases.

    E. The gas in the container does positive work on the piston.

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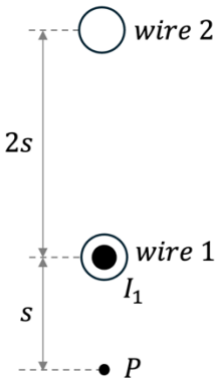
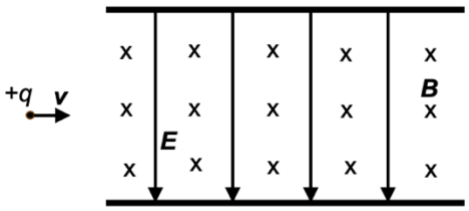
II. Lecture long-answer questions (20 points total)

13. [5 pts] Two current-carrying wires, 1 and 2, are arranged as shown at right. The current in wire 1 is flowing out of the page and has magnitude I_1. The distances of wires 1 and 2 from point *P* are *s* and 3*s* respectively, and the magnitude of the magnetic field at point *P* is zero.



What is the direction and the magnitude of the current in wire 2? Write the magnitude in terms of I_1. Explain your reasoning.

14. [5 pts] A positive point charge $+q$ moves with a speed v in the positive-*x* direction. The charge enters a region where the electric field is uniform and points in the negative-*y* direction as shown. The same region also contains a uniform magnetic field pointing into the page.



What is the ratio E/B of the magnitudes of the electric and magnetic fields, if the point charge moves through the region without deflection? You can ignore gravitational forces. Explain.

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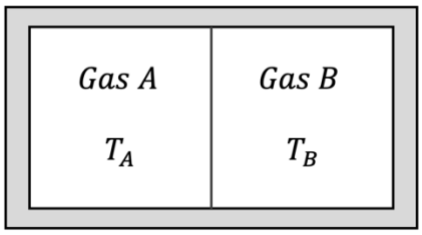
A small, closed syringe is filled with air that has been cooled down 5℃ in a fridge. The syringe is then taken to a room that has an air temperature of 20℃. The syringe is allowed to come to thermal equilibrium with the room.

15. [4 pts] Now, the plunger of the syringe is pushed down very rapidly and the temperature of the air inside the syringe is observed to increase. How do you explain this observation?

Two containers, A and B, contain ideal gases consisting of atoms of masses m_A and m_B, and root-mean-square speeds $v_{rms,A}$ and $v_{rms,B}$, respectively. The gases do not mix with each other, but they are in thermal contact. At $t = t_0$, the gases are at temperatures T_A and T_B, respectively.



16. [3 pts] In terms of the given quantities, what is the ratio of the average kinetic energies of the atoms in containers A and B at $t = t_0$? Show your work.

17. [3 pts] In terms of the given quantities, (i) what is the ratio of the average kinetic energies of the atoms in containers A and B and (ii) the ratio of their root-mean-square speeds a long time after $t = t_0$,? Show your work.

Name _____ **UW Net ID** _____
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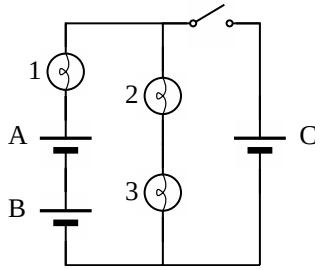
III. Tutorial and lab long answer questions (20 points total)

The circuit at right contains ideal identical batteries and identical bulbs.



18. [5 pts] When the switch is closed, does the brightness of bulb 3 *increase*, *decrease*, or *remain the same* compared to the brightness of bulb 3 when the switch is open?

19. [5 pts] While the switch is closed, is bulb 1 *brighter than*, *dimmer than*, or *as bright as* bulb 2? Explain.

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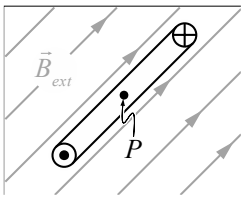
20. [5 pts] The diagram at right depicts a positively charged particle located near a current carrying wire (current is out of the page). The particle moves to the right at point A as shown. In the box provided, indicate the direction of the magnetic force experienced. If the force is either into or out of the page, use the appropriate symbols. Explain.

Force direction

21. [5 pts] A small loop of wire is placed in a region with a uniform magnetic field $\vec{B}_{ext}$ that does not change with time. The loop is attached to a battery (not shown) so that there is a current through it as shown in the cross-sectional diagram at right. The center of the loop is at point *P*.



Note: The symbol ⊗ indicates current into the page and the symbol ⊙ indicates current out of the page.

Is the magnitude of the net magnetic field at point *P greater than, less than,* or *equal to* the magnitude of $\vec{B}_{ext}$? Explain your reasoning.