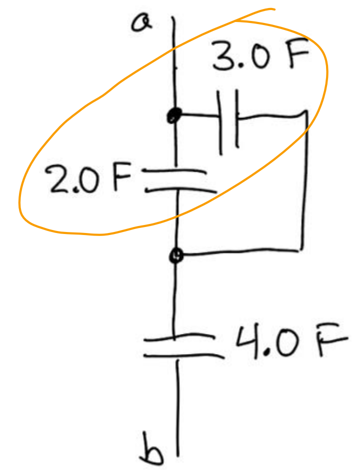
Q1–Q15: Lecture multiple choice — Fill in the correct answer on your bubble sheet.

1. [4 pts] The circuit diagram at right represents a small part of a much larger circuit. Suppose all three capacitors between points *a* and *b* were replaced with a single capacitor such that the rest of the circuit's behavior remained unchanged. What is the capacitance of that single capacitor?



$C_{equiv} = 5\ F$

A. 0.92 F
B. 1.6 F
C. 2.2 F
D. 5.2 F
E. 9.0 F

$$C_{equiv} = \frac{1}{\frac{1}{5F} + \frac{1}{4F}} = 2.2F$$

2. [4 pts] An ideal 10-volt battery, an ohmic resistor, a switch, and a 0.10-farad capacitor that is initially uncharged are all arranged in a single-loop circuit. The switch is closed at $t = 0$. The current through the resistor at $t = 0$ is 0.50 amps.

   What is the current through the resistor at $t = 1.0$ s?

A. 0.18 amps
B. 0.30 amps
C. 0.40 amps
D. 0.48 amps
E. 0.55 amps

Get resistance R: At $t = 0$, $R = \frac{\mathcal{E}}{I_0} = \frac{10\ V}{0.5\ A} = 20\ \Omega$

At $t = 1.0\ s$: $I = (0.50\ A)e^{-(1.0\ s)/(20 \times 0.10\ s)}$
$= 0.30\ A$

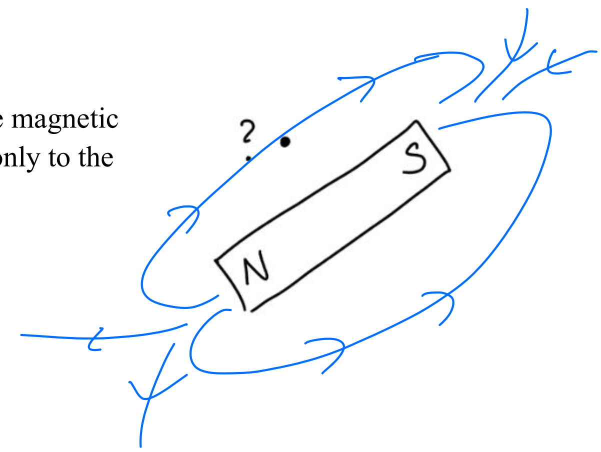
3. [4 pts] Electrical signal transmission along nerve cell axons can be modeled, in part, as multiple RC circuits. The amount of time for a signal to propagate from one location to another is directly related to the time constant $\tau = RC$. Suppose that the distance between the ‘parallel plates’ of the capacitors in this model is **increased.** How would this change affect the **amount of time** it takes for an electrical signal to propagate across nerve cells?

A. The time would increase
B. The time would decrease
C. The time would remain the same
D. None of these are correct.

$\tau = RC$

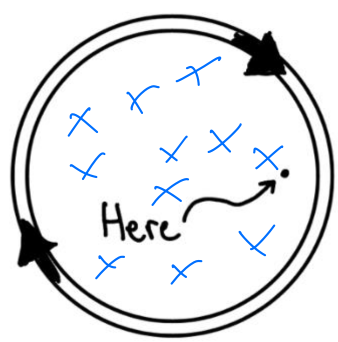
$d\uparrow \Rightarrow C\downarrow \Rightarrow \tau\downarrow$

4. [4 pts] Which option below best represents the direction of the magnetic field at the indicated point? Assume the magnetic field is due only to the shown bar magnet.



A. ⊗ (into the page)
B. ↙
C. ↗
D. ↑
E. ←

5. [4 pts] A circular loop of wire carries current clockwise, as shown. What is the direction of the magnetic field at the indicated point? Assume that the point is located in the plane of the loop.



A. ⊗ (into the page)
B. ⊙ (out of the page)
C. →
D. ←
E. ↗

Use RHR on any portion of the wire.

6. [4 pts] A single circular loop of current with **diameter** 10 cm = 0.10 m is oriented so that the magnetic field it produces at the center of the loop is oriented opposite the magnetic field produced by the Earth. If the Earth has magnetic field $50\ \mu\text{T} = 50 \times 10^{-6}$ T, what is the current in the loop if the **net** magnetic field at the center of the loop is zero?

A. 0 amps

B. 1.4 amps

C. 2.7

D. 4.0 amps

E. 7.9 amps

$$B = \frac{\mu_0 I}{2R}$$

$$\Rightarrow I = \frac{2RB}{\mu_0}$$

$$= \frac{2 \times (0.05\ \text{m})(50 \times 10^{-6}\ \text{T})}{1.26 \times 10^{-6}\ \text{T m/A}}$$

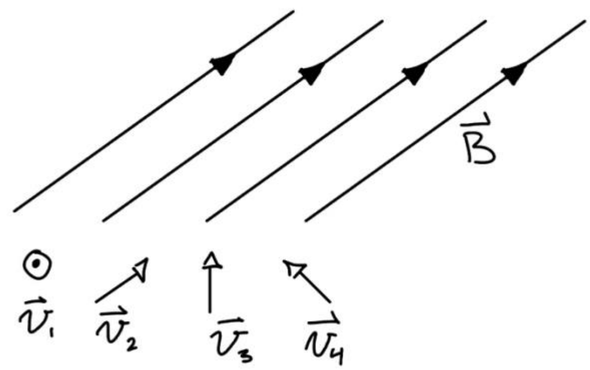
$$= 3.96\ \text{A} \rightarrow \boxed{4.0\ \text{A}}$$

7. [4 pts] Suppose you want a large 3-dimensional region of space to contain a **uniform** magnetic field. Which of the following regions and current configurations would best accomplish this?

   A. Directly between two magnets with their north poles (or south poles) facing each other
   B. Outside of an infinitely long wire that carries **constant** current
   C. Outside of an infinitely long wire that carries an **exponentially decreasing** current
   D. The region immediately around a compass.
   E. Inside of a solenoid

B is uniform inside ideal solenoid.

8. [4 pts] Consider the region of uniform magnetic field shown at right. The four vectors labeled $\vec{v}_1$ through $\vec{v}_4$ represent possible velocities of a charged particle. The speeds corresponding to each velocity are identical. Note that $\vec{v}_4$ is perpendicular to the B-field.



   Rank the magnitude of the resulting magnetic force vector for each of the four possible velocity vectors.

   A. $F_4 = F_3 > F_2 > F_1$
   B. $F_2 > F_3 > F_1 > F_4$
   C. $F_2 > F_3 > F_4 > F_1$
   D. $F_4 > F_3 > F_2 > F_1$
   E. $F_1 = F_4 > F_3 > F_2$

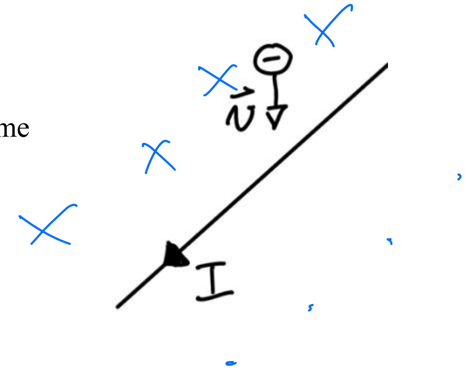
Both cases 1 and 4 have a $\vec{v}$ that is $\perp$ to B.

$F = |q| v B \sin\theta$

$\Rightarrow F_1 = F_4 > F_3 > F_2 = 0$

parallel so $\theta = 0$

9. [4 pts] A long wire carries current in the direction shown (diagonally down-and-left). What is the direction of the magnetic force on the **negatively charged** particle moving in the indicated direction? Assume both the wire and the velocity vector are in the plane of the paper.



A. ⊗ (into the page)

B. ⊙ (out of the page)

C. ↗

D. ←

E. None of these are correct

$\vec{B}$ is into page at loc. of charge. RHR of $\vec{v} \times \vec{B}$ gives a RIGHTWARD force, but $q<0$ so $\vec{F}$ is LEFTWARD

10. [4 pts] The wire shown carries current 4.0 A to the right. A uniform magnetic field of magnitude 2.0 T is indicated. What is the magnitude of the magnetic force exerted on a 1.0-cm region of the wire?

A. 0 N

B. 0.080 N

C. 0.80 N

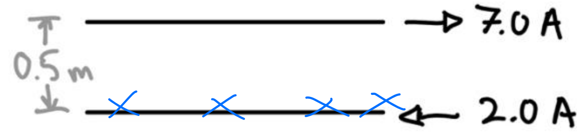
D. 8.0 N

E. None of these are correct

$F = ILB\sin\theta$

$\theta = 0$ so $F = 0$

11. [4 pts] Two very long, parallel wires are situated 0.50 m apart from each other. The top wire carries 7.0 A of current rightward and the bottom carries 2.0 A of current leftward.



Is the magnetic force between the two wires attractive and repulsive, and what is the magnitude of the force exerted on a 3.0-meter length of the bottom wire?

A. Attractive, 1.7×10^{-5} N

B. Attractive, 4.7×10^{-7} N

C. Repulsive, 3.2×10^{-6} N

D. Repulsive, 1.3×10^{-6} N

E. None of these are completely correct

$\vec{B}$ due to top wire is into page at bottom wire's loc. This causes a DOWNWARD force on bottom wire (so REPULSIVE) with magnitude

$F = ILB = (2A)(3m)\frac{\mu_0 I_{top}}{2\pi R}$

$= (6\ A\cdot m)\left(\frac{1.26\times10^{-6}\ T\cdot m/A \times 7\ A}{2\pi\ 0.5\ m}\right)$

$= 1.7\times10^{-5}\ N$ Repulsive

12. [4 pts] The metabolic power of a 68-kg person who is swimming quickly is 800 W. How much **mechanical work** in Calories (kcal) does such a person do **on the water** during a 1-minute swim? Use the conversion 1 Calorie = 4,186 J. Recall that the efficiency of the human body for physical activity is 25%.

A. 0.19 Cal

B. 0.76 Cal

C. 1.5

D. 2.9 Cal

E. 11 Cal

$e = \frac{\text{want}}{\text{pay}} = 0.25 = \frac{W}{\Delta E_{metabolic}}$

$\Rightarrow W = 0.25 \times (800\ \frac{J}{s} \cdot 60\ s) = 1200\ J \times \frac{1\ Cal}{4{,}186\ J}$

$= 2.9\ Cal$

13. [4 pts] You have a container of 0 °C liquid water in which you place an ice cube that is also at 0 °C. Which of the following best describes the heat flow between the two substances if they are put into contact?

A. Heat flows from the water to the ice.

B. Heat flows from the ice to the water.

C. Heat does not flow between the two.

Same temp.

14. [4 pts] Sample A contains an unknown amount of helium gas, which is the lightest monatomic gas. Sample B contains an unknown amount of xenon gas, which is also monatomic. The pressures, volumes, and amount of gas particles are unknown, but it is known that the root-mean-square speeds of the two samples of gas are the same. How do the temperatures of the samples compare?

A. Sample A (helium) has greater temperature.

B. Sample B (xenon) has greater temperature

C. Both samples have identical temperatures

D. Impossible to determine

$T \propto KE \propto m(v^2)_{avg}$

$\Rightarrow$ same $(v^2)_{avg}$ but greater mass m for xenon means a greater temperature for xenon

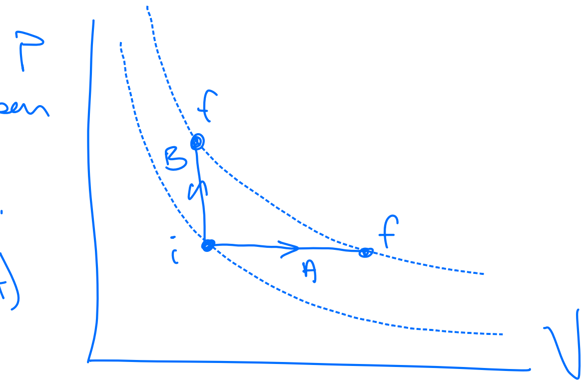
15. [4 pts] In Experiment A, an isobaric process is performed on a sample of gas in which the temperature of the gas goes from 300 K to 400 K. In Experiment B, an isochoric process is performed on an identical sample of gas in which the temperature goes from 300 K to 400 K. How does the work done **by the gas** on the environment compare in the two experiments? Negative work should be considered as being *less* than zero or positive work.

A. Greater work is done by the gas in Experiment A

B. Greater work is done by the gas in Experiment B

C. Equal works done in both experiments

$W_{by\,gas}$ = area between pV-curve and horiz. axis. (positive to right)



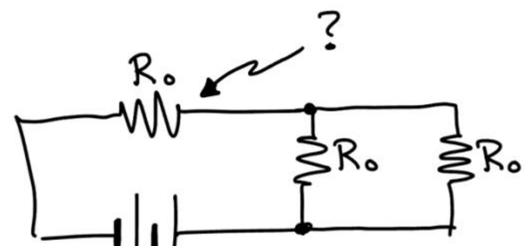
$\Rightarrow W_{by\,gas,A} > 0$

$W_{by\,gas,B} = 0$

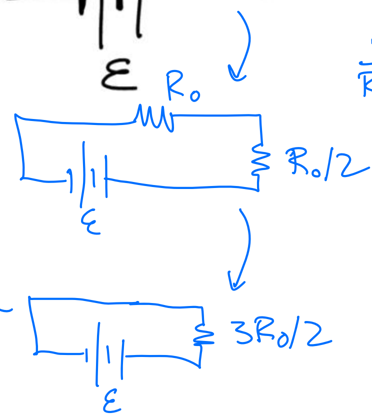
$\Rightarrow W_A > W_B$

Q16–Q20: Lecture free-response — Unless otherwise noted, explain your reasoning or show your work.

16. [4 pts] An ideal battery (emf $\mathcal{E}$) and three identical resistors (resistance R_0) are arranged as shown. Determine the absolute values of the <u>current through</u> and <u>voltage across</u> the top resistor (i.e., the one indicated by a '?') in terms of the given variables. Show your work.



The circuit simplifies to a single $3R_0/2$ resistor, so current through it is $I = \frac{\varepsilon}{3R_0/2} = \frac{2}{3}\frac{\varepsilon}{R_0}$.

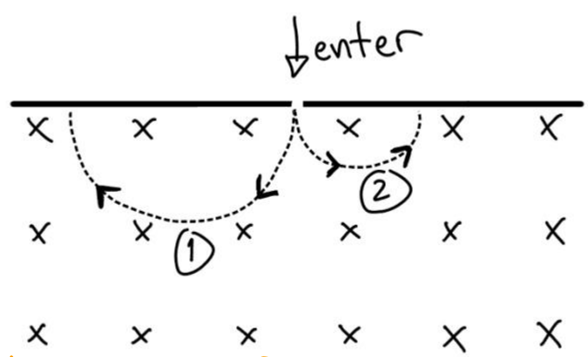


$\frac{1}{R_0} + \frac{1}{R_0} = \frac{2}{R_0}$

Re-expanding, the current through the top resistor is also $\frac{2}{3}\frac{\varepsilon}{R_0}$ (current same in series) so voltage is

$$|\Delta V| = IR_0 = \frac{2}{3}\frac{\varepsilon}{R_0}\cdot R_0 = \boxed{\frac{2}{3}\varepsilon}$$

17. [4 pts] Particles 1 and 2 have identical masses ($m_1 = m_2$) and identical absolute values of charge ($|q_1| = |q_2|$). The two particles enter a region of uniform magnetic field and undergo the trajectories shown.



Is the **amount of time** it takes particle 1 to complete its half-circular trajectory <u>greater than</u>, <u>less than</u>, or <u>equal to</u> the amount of time it takes particle 2 to complete its half-circular trajectory? Show your work. Ignore gravity.

half of circumference

Time is $T = \frac{\pi r}{v}$ where r is the radius of semi-circular trajectory. The radius r is $r = \frac{mv}{|q|B}$ (appropriate for moving particle in uniform B-field). Plug in:

$$T = \frac{\pi}{v}\frac{mv}{|q|B} = \frac{\pi m}{|q|B}.$$

Since m, $|q|$, and $|B|$ are all the same, then $\boxed{\text{times are the same}}$

18. [4 pts] During some process, a system does 400 J of work on the environment, and the thermal energy of the system increases by 300 J.

(i) [2 pts] Determine a numerical value in joules for the **amount of heat** that flows into the system (*positive* for flow *into* the system, as usual). Show your work.

$W_{by\ gas} = +400\ J$ → Note $W_{on\ gas} = -400\ J$

$\Delta E_{th} = +300\ J$

First law of thermo:

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

$\Rightarrow Q = \Delta E_{th} + W_{by\ gas}$

$= 300\ J + 400\ J = \boxed{700\ J}$

(ii) [2 pts] During the process, was the system hotter or the environment hotter? Explain.

From (i), heat flowed into system ($Q>0$), so environment was hotter since heat flows from hot to cold.

19. [4 pts] A hot object (Object A) exchanges 7 J of heat with cool object (Object B). Assume the objects are large enough that any change in temperature is negligible.

Is the change in entropy of the two-object system positive, negative, or zero? Assume no other heat exchanges occur. Explain or show your work.

- Heat flowed from A to B (hot to cold)

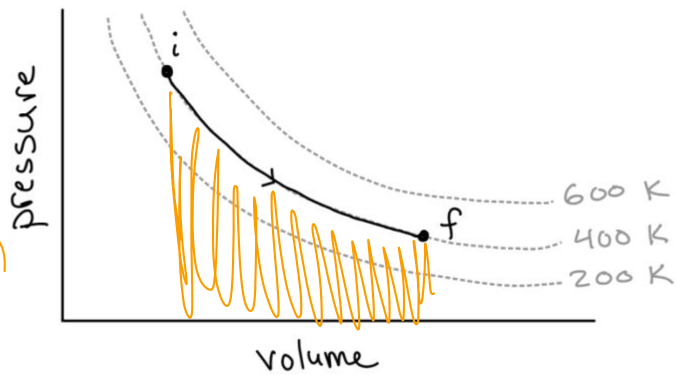
Any of these explanations are sufficient:

↳ This process is irreversible because we never observe the reverse — heat from cold to hot. All irreversible processes have positive entropy change

↳ $\Delta S_{tot} = \Delta S_A + \Delta S_B = \frac{Q_{to\ A}}{T_A} + \frac{Q_{to\ B}}{T_B} = \frac{-7\ J}{T_{hot}} + \frac{+7\ J}{T_{cold}} > 0$

greater absolute value since $T_{cold} < T_{hot}$

20. [4 pts] A sample of gas undergoes the process shown at right. Is the heat flow into the gas during this process <u>positive</u>, <u>negative</u>, or <u>zero</u>? Explain or show your work.



0 (isothermal $\Delta T = 0$)

$Q_{to\ gas} = \cancel{\Delta E_{th}} + W_{by\ gas}$

area under curve, shaded

$= 0 +$ positive quantity

$\Delta V > 0$ so $W_{by\ gas} > 0$

> 0 **positive**

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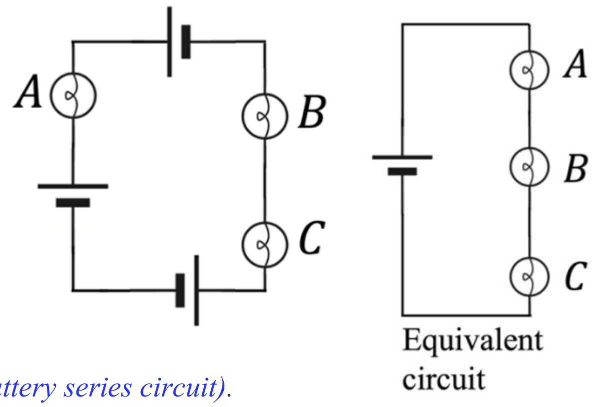
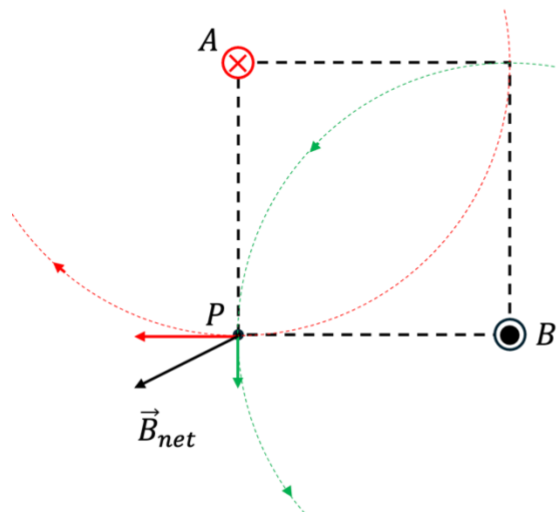
In the circuits at right, all bulbs are identical, and all batteries are ideal and identical.



21. [4 pts] Rank the bulbs A-C according to brightness, from brightest to dimmest. If any bulbs do not light, state so explicitly. Explain your reasoning.

The circuit at right is a single loop circuit with all elements connected in series. Two batteries are connected in reverse orientation, which results in an effective voltage of a single battery. All bulbs have equal brightness and are lit (each bulb is equal in brightness to a bulb in a three-bulb, single battery series circuit).

A long wire, wire A, carries a current I_0 into the page. A second wire, wire B, is located as shown. At point P, the net magnetic field points as shown (the wires are equidistant from point P).



22. [4 pts] Does wire B carry a current into or out of the page? Explain.

The magnetic field of wire A is clockwise around wire A by the RHR. At point P, the magnetic field of wire A is tangent to this circle, which points directly to the left (red arrow).

The field around wire B is also circular and centered on wire B. A tangent to this circle at point P can either point directly upward or directly downward. For the net field to point to the downward to the left at point P, the magnetic field at point P due to wire B must point directly downward. By RHR, the current in wire B must be out of the page.

23. [4 pts] Is the current in wire B *greater than, less than* or *equal to* I_0? Explain.

The x-component of the net magnetic field at point P is larger than the y-component. The x-component is due to wire A and the y-component is due to wire B. We can thus conclude that $|\vec{B}_{wire\ A}| > |\vec{B}_{wire\ B}|$. *Since both wires are equidistant from point P, and the magnetic field is proportional to the current in the wire, the current through wire B must be* ***less than*** *that through wire A.*

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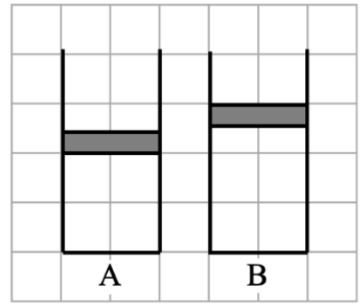
The figure at right shows two identical cylinders, A and B that are fitted with identical pistons. Each piston is free to move without friction. Both cylinders have been in the same room for a long time. Cylinder A contains an ideal gas with a larger molecular mass than the ideal gas in cylinder B.



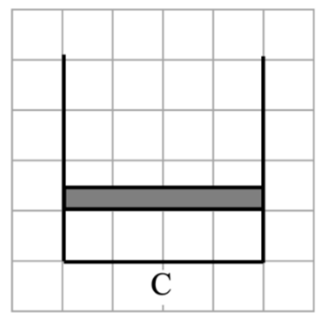
24. [4 pts] Is the pressure of the gas in cylinder A *greater than, less than,* or *equal to* the pressure of the gas in cylinder B? Explain. If not enough information is given, state so explicitly.

Since the cylinders are identical and the pistons are identical, we can conclude that the pressure of the gases in each cylinder are ***equal to*** *each other since we can define the pressure of the gas as follows:*

$$P_{gas} = P_{atm} + mg/A$$

The mass and cross-sectional area of each piston is the same, so the pressure of each gas is the same.

Cylinder C has a diameter that is twice as large as that of cylinder A and the mass of piston in cylinder C is four times larger than that of cylinder A. The cylinders have been in the same room for a long time, and the height of piston A is twice as high as that in cylinder C.



25. [4 pts] Is the number of particles in container C *greater than*, *less than*, or *equal to* the number of particles in container A? Explain.

By using the logic from the previous question, we can conclude that the pressure of the gas in cylinder A is the same as that in cylinder C. (Since the diameter of cylinder C is twice as large as that of cylinder A, the cross-sectional area of the piston in cylinder C is four times larger than the cross-sectional area of the piston in cylinder A.)

$$P_{gas,A} = P_{atm} + mg/A$$

$$P_{gas,C} = P_{atm} + \frac{4mg}{4A} = P_{gas,A}$$

We can write the number of particles in cylinder A as:

$$N_A = \frac{P_A V_A}{k_B T_A}$$

We know the pressures and the temperatures are the same, so the number of particles is proportional to the volume. Cylinder C has twice the volume of cylinder C, so the number of particles is greater than that in cylinder A.

$$V_A = A_A h_A \quad V_C = 4A_A \frac{h_A}{2} = 2V_A$$