Question 1: A container of oxygen (O_2) gas and an identical container with neon (Ne) gas are each heated from 273K to 300K (at constant volume), and it is found that the same amount of energy is required in each case. We can say that

O_2: higher molar specific heat since some energy goes to rotational K.E.

A) The number of moles of O_2 is the same as the number of moles of Ne. ∴ same moles would mean O_2 takes more energy

B) The number of moles of O_2 is greater than as the number of moles of Ne.

(C) The number of moles of O_2 is less than as the number of moles of Ne.

D) Any of the above are possible

- since same energy, must be less moles O_2

Question 2: Two identical containers are each filled with helium. In the first container, the average speed of the atoms is twice the average speed in the second container. If the gas in each container has the same pressure, we can say that

pressure $\propto$ density × (avg K.E. per molecule)

density × $\frac{1}{2}mv^2$

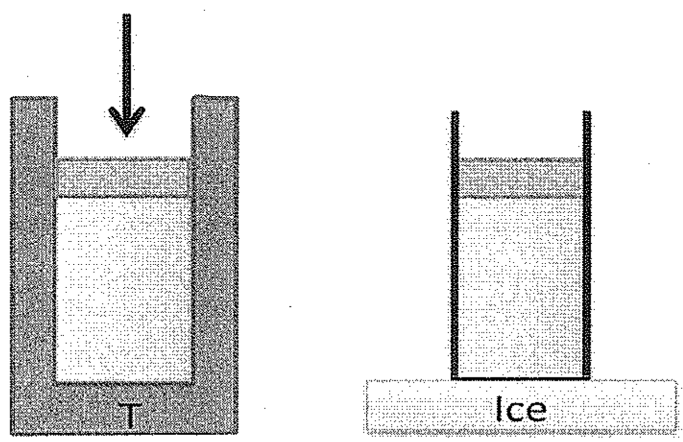
if v is double & pressure same, density must be $\frac{1}{4}$

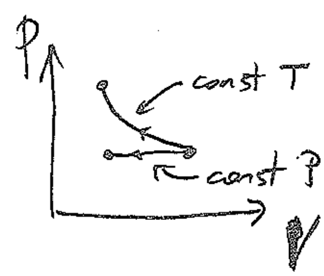
A) The density in the first container is four times larger

B) The density in the first container is two times larger

C) The density in the first container is two times smaller

(D) The density in the first container is four times smaller





work = area under path.
- greater for const T

Question 3: Two containers each contain one mole of oxygen, each with the same initial volume, temperature, and pressure. One is compressed while being kept at constant temperature, while the other is cooled with a freely moving piston. If the volume is decreased by half in each case, we can say that

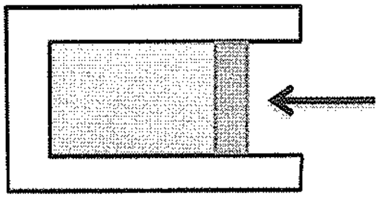
(A) The work done on the gas is nonzero in both cases but larger in the constant temperature case

B) The work done on the gas is nonzero in both cases, but smaller in the constant temperature case

C) The work done on the gas is nonzero only in the constant temperature case

D) The work done on the gas is nonzero only in the case where the gas is cooled

other way: Work = $\int P dV$ P increases in the const temp process, so $\text{work}_{(\text{const } T)} > P_0 \Delta V = \text{work (const P)}$



~~Adiabatic~~:
Insulated: $Q = 0$ so $\Delta E = W$

we do work ∴ W +ve, ΔE +ve ∴ temperature increases

Ideal gas Law: T↑ V↓ so must have P↑

Question 4: Gas in an insulated container is compressed. We can say that

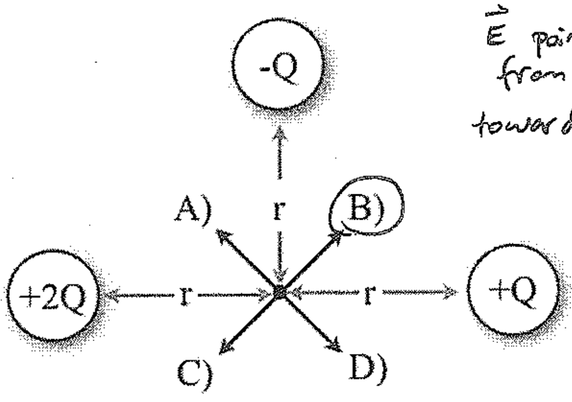
A) The temperature of the gas increases and the pressure stays constant
B) The temperature of the gas stays constant and the pressure increases
(C) The temperature and pressure of the gas both increase
D) The temperature of the gas decreases and the pressure increases
E) The temperature and pressure of the gas both decrease

Question 5: Equal amounts of helium gas fill two halves of an isolated container with a thermally conducting partition in the middle. Initially, the temperature is 300K on one side and 400K on the other side. If we observe the gas some time later, we can be sure that the temperatures on the two sides will never be 275K and 425K, because

A) this would violate conservation of energy. — energy conserved — only problem is far fewer total states with T = 275K, 425K
B) this would violate the ideal gas law.
C) the partition allows heat to flow from one side to the other, but the temperatures cannot change if the two gases do not mix. ∴ going to this config impossibly unlikely
(D) this would be extraordinarily unlikely.

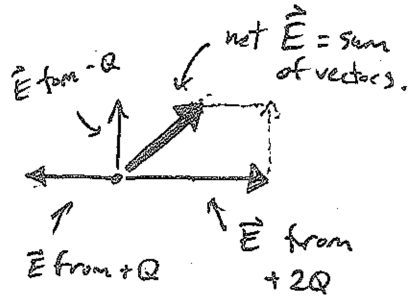
(= violation of 2nd Law)

Question 6: A point in empty space is equidistant from 3 charges as shown. What is the direction of the electric field at that point?

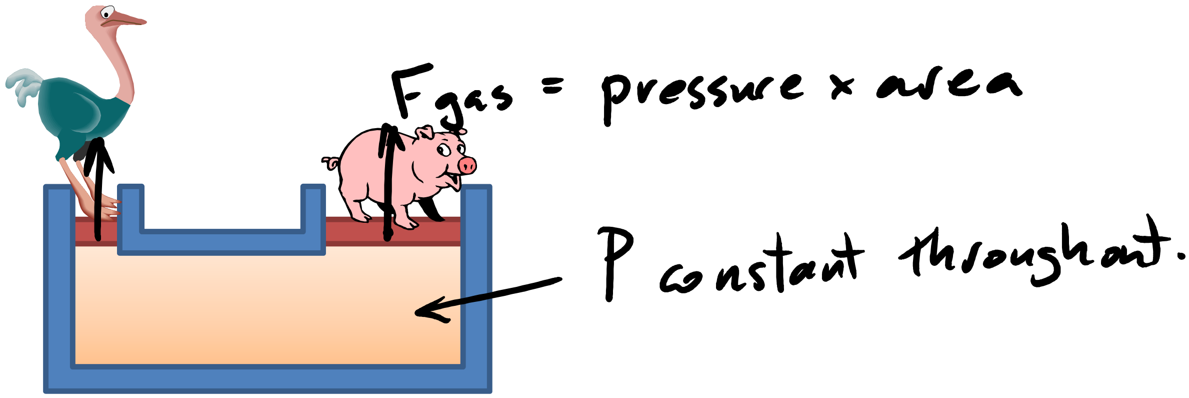


$\vec{E}$ points away from + towards −

size of $\vec{E}$ ∝ Q



E) None of the angles shown

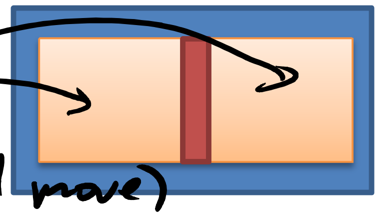


Question 1: In the picture above, the gas in the container has a uniform pressure throughout and the two pistons are freely movable. If the system is in equilibrium as shown, we can say that

A) the ostrich is heavier than the pig.
B) the pig is heavier than the ostrich.
C) the pig and the ostrich are the same weight.

more upward force from gas on pig side.

∴ mg for pig is greater (balanced by force of gas) same pressure on both sides (or piston would move)



Ideal gas law: $n = \frac{PV}{RT}$

Question 2: In the picture above, the container holds neon gas on the left and helium gas on the right (with equal volumes). If the temperature is the same on both sides and the barrier in the middle is a freely movable piston, we can say that

A) The number of moles of neon gas is greater
B) The number of moles of helium gas is greater
C) The number of moles of helium equals the number of moles of neon
D) There is not enough information to say which of A, B, or C is correct

Same P, V, T so same n

Question 3: In the previous question, we can say that

A) The average speed of the neon molecules is greater
B) The average speed of the helium molecules is greater
C) The average speed of the helium molecules is the same as the average speed of the neon molecules
D) There is not enough information to say which of A,B, and C is correct

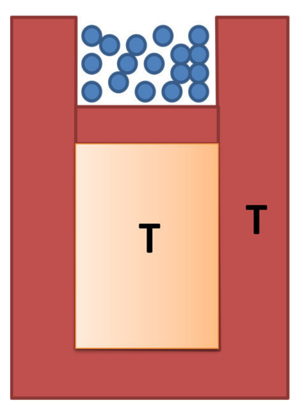
T same so $\frac{1}{2} m_{He} \cdot V_{He}^2 = \frac{1}{2} m_{Ne} \cdot V_{Ne}^2$

$m_{Ne} > m_{He}$

so V_{He} is larger

Question 4: In the picture above, a bunch of marbles sit on top of a freely movable piston. If the marbles are removed one by one while the gas inside the cylinder is kept at constant temperature, we can say that

A) heat flows into the gas.
B) heat flows out of the gas.
C) no heat flows into or out of the gas.



W negative for expanding gas.

gas will expand since outside force decreases.

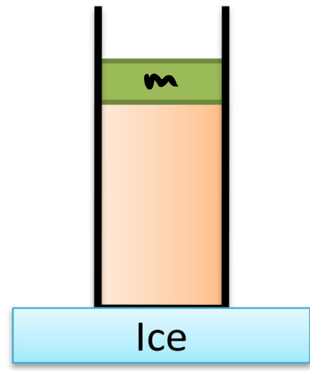
const T $\Rightarrow \Delta E = 0$

$\therefore Q = -W$
$= \text{positive}$

heat flows in & is converted to work

Question 5: Gas in a cylinder with a freely moving piston is cooled so that its volume decreases. In this process,

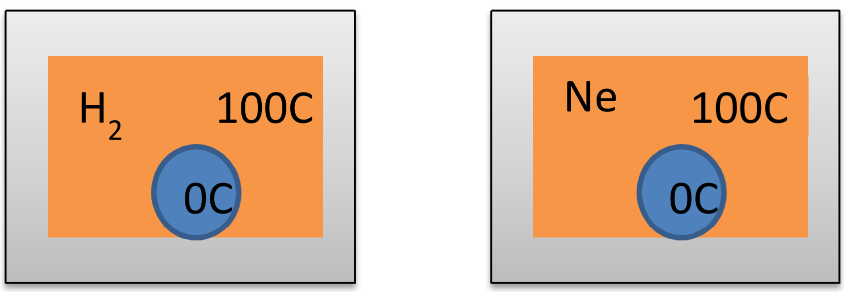
A) The pressure increases
B) The pressure decreases
C) The pressure stays the same



$P = P_{atm} + mg \cdot Area$

$= constant.$

isobaric



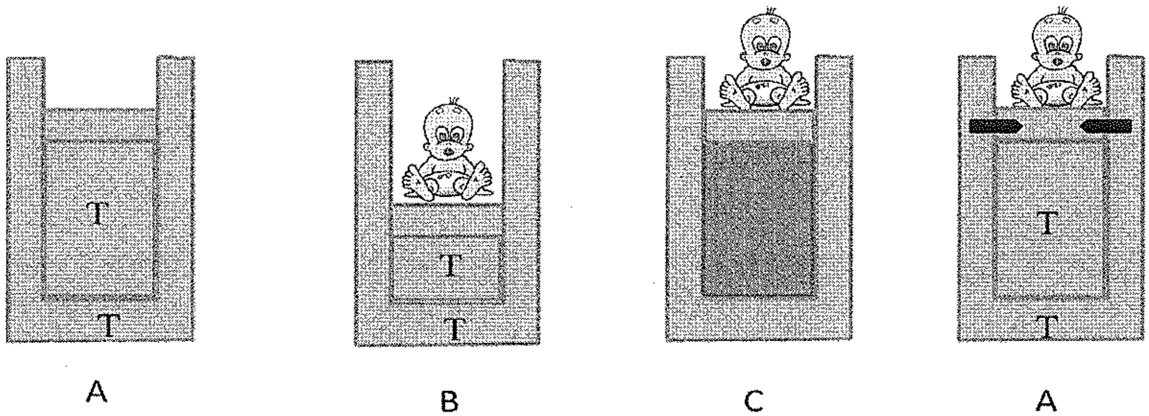
C_v higher for H_2 so less ΔT for same change in energy.

Final temp of penny + gas will be the same.

Question 6: Two identical containers with insulating walls contain 1 mole of H_2 gas and one mole of Ne gas, each at 100 degrees Celsius. Two identical pennies, each with an initial temperature of 0 degrees Celsius, are placed in the two containers. After each system reaches equilibrium, we can say that

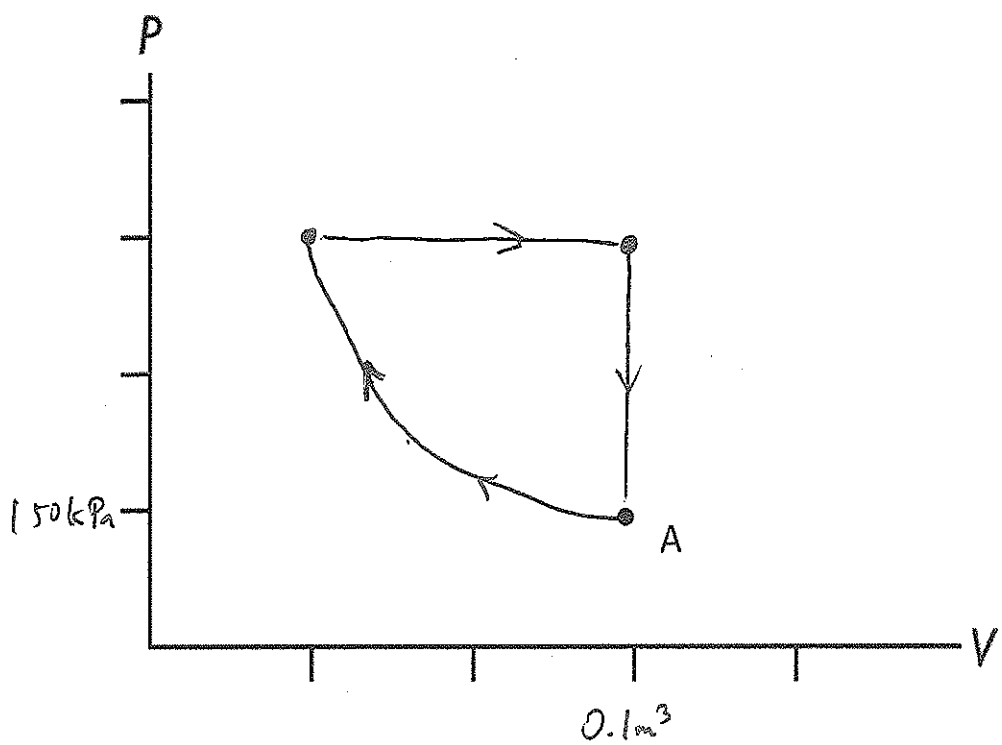
A) the penny in the neon gas will be hotter.
B) the penny in the hydrogen gas will be hotter.
C) both pennies will have the same final temperature.

If final temp of neon penny is T_N, H_2 gas will be hotter than T_N when penny reaches T_N, since it's temperature changes less than the neon gas for a fixed change in energy (energy needed to heat the penny to T_N).



Question 12 (8 points):
You are about to submit a patent application for a gasoline-powered device to entertain babies. The device consists of a vertical cylinder of gas with a movable piston surrounded by a constant temperature water bath. The gas inside is originally at the same temperature as the water bath.

To use the device, a baby is placed on top of the piston so that the gas is slowly compressed to one third of its volume at constant temperature (A → B). Then fuel is added to the gas and burned slowly so that the gas heats and expands to its original volume while the piston on top is free to move (B → C). Finally, the piston is locked and the gas cools again to the temperature of the water bath (C → A). The piston locks are removed and the process repeats. The baby is entertained by the gentle up and down motion. (*see next page for questions*)



a) Draw the process on the graph above and fill in the chart below given the initial values for the state A. Explain your work in the space below the table.

	A	B	C
Temperature	300K	300 K	900 K
Pressure	150kPa	450 kPa.	450kPa
Volume	$0.1m^3$	$0.0333 m^3$	$0.1 m^3$

A→B : const T

∴ PV constant (I. Gas Law)

∴ P triples if $V \Rightarrow V \times \frac{1}{3}$

B→C : const P

∴ T/V const (ideal gas law)

∴ T triples if V triples

C→A : constant V.

b) Suppose the gas in the cylinder is argon, with $C_V = 3/2\ R$. How much gasoline (35MJ/L) must be burned each cycle to entertain the baby? (Hint: the question is basically asking how much heat must be added to the gas in the process B → C).

for $B \to C$,

$$\Delta E = Q + W$$

Have: $W = -P\Delta V$ (since const pressure)

$$= -3 \times 10^4\ J$$

$$\Delta E = n C_V \Delta T$$

$$C_V = \frac{3}{2} R$$

$$\Delta T = 600k$$

$$n = \frac{P_A V_A}{R T_A} = 6.02\text{moles}$$

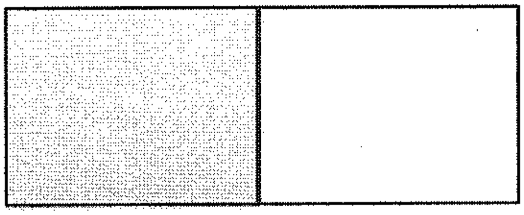
So $\Delta E = 4.5 \times 10^4\ J$

Thus: $Q = \Delta E - W$

$$= 7.5 \times 10^4\ J$$

We need to burn a volume $\frac{7.5 \times 10^4 J}{35\ MJ/L} = 2.1\ mL$

of gasoline per cycle.



Question 13 (4 points + possible bonus points):

A container with a partition in the middle has two sides with volume $1 m^3$. The container is filled on one side with a "gas" of 10^9 free electrons with temperature 300K. If the partition is removed so that the electrons fill the container, does the temperature increase, decrease, or stay the same? Explain. If you predict that the temperature will change, estimate the final temperature.

We have energy conserved.

The potential energy of the electrons is higher when they are closer together.

Thus, $\Delta U < 0$ when the gas expands.

So $\Delta K > 0$: the average kinetic energy of the electrons must increase.

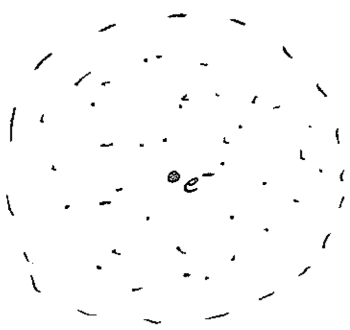
Thus, the temperature goes up.

Have: increase in T

$$= \frac{2}{3k_B} \times (\text{increase in avg K.E.})$$

$$= \frac{2}{3k_B} \times (\text{decrease in avg potential energy})$$

So we need to estimate the average potential energy per electron.



To simplify, imagine an electron in the middle of a spherical volume V, with a total of N electrons in this volume. The potential energy of this electron is

$$\mathcal{U} = \sum_{\substack{\text{other} \\ \text{electrons} \\ i}} \frac{ke^2}{r_i} \leftarrow \text{distance to middle.}$$

very crude estimate: - N terms in sum

- typical value of $\frac{1}{r}$ is $\frac{1}{V^{1/3}}$

$$\therefore \ \mathcal{U} \approx \frac{ke^2 N}{V^{1/3}}$$

better:

Contribution from shell of radius r, thickness dr:

$$n = (4\pi r^2 \, dr) \times \rho \quad \text{electrons in shell}$$

($4\pi r^2 \, dr$ ← volume, ρ ← density)

$$\rho = \frac{N}{V}$$

$$\therefore \text{ contribution is } \left(4\pi r^2 dr \times \frac{N}{V}\right) \times \frac{ke^2}{r}$$

Add up from $r=0$ to $r = \left(\frac{3}{4\pi} V\right)^{\frac{1}{3}}$ (i.e. radius of sphere)

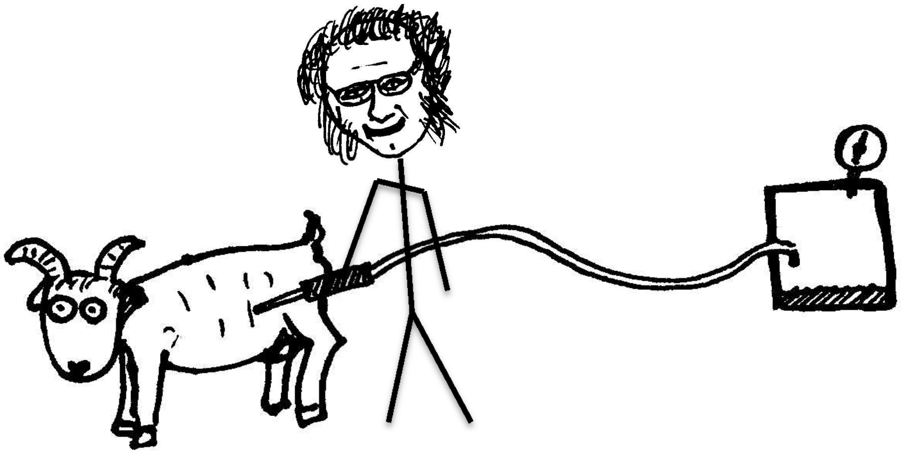
$$\mathcal{U} = \int_0^{\left(\frac{3}{4\pi}V\right)^{\frac{1}{3}}} \frac{N}{V} 4\pi r^2 \frac{ke^2}{r} \, dr$$

$$= \frac{ke^2 N}{V^{1/3}} \cdot \frac{3^{2/3}}{2 \cdot (4\pi)^{1/3}}$$

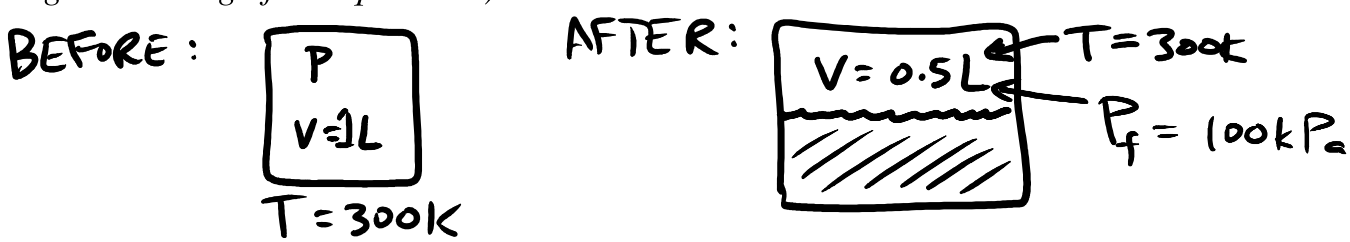
almost the same as our crude estimate.

Rough estimate of ΔT is then

$$\frac{2}{3k_B} \left(ke^2 N\right) \left(\frac{1}{V_i^{1/3}} - \frac{1}{V_f^{1/3}}\right) \approx 10^5 \, K$$



Question 33: One day at Jim's Antibody Ranch, Jim decides to test out a new method for bleeding a goat. Jim connects a syringe to a hose which feeds into a fixed-volume 1L container filled with argon gas at a low pressure P. Blood flows into the container, compressing the gas. The flow stops when the pressure of the argon is 100kPa. If Jim wants to extract half a liter of blood from the goat, what should the initial pressure of the argon gas be? Assume that the gas temperature remains at 300K throughout. *(**NOTE ADDED:** taken out of context, this question may seem really twisted. Everything will make more sense after term 2 biology... . No actual goats were bled during the making of this question.)*



Ideal gas law: T constant, so PV constant.

So $P \cdot (1L) = (100kPa) \cdot (0.5L)$

$\Rightarrow P = 50kPa$

Part b:
Jim wants to do a winter bleed, so he uses an insulated container and an insulated hose to make sure the blood doesn't freeze. Suppose that the argon gas is initially at 260K and the temperature of the blood is 310K. As the blood enters the container, heat flows from the blood to the gas so that the blood and gas are always at the same temperature. In this case, what should be the initial pressure in the cylinder and what is the final temperature of the blood?
(According to Wikipedia, the heat capacity of goat blood is 3600 J/(LK) (Joules per liter per degree Kelvin)

Ideal gas Law:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow P \cdot T_f = 0.5 \cdot 100kPa \cdot 260K$$

Energy conservation:

$$\Delta E_{gas} = \Delta E_{blood}$$

$$n c_v \cdot (T_f - 260K) = c_{BLOOD} \cdot (0.5\,L) \cdot (310K - T_f)$$

$n \leftarrow \frac{P_2 V_2}{T_f}$, $c_v \leftarrow \frac{3}{2} R$, $c_{BLOOD} \leftarrow 3600\, J/L \cdot K$

Can solve this for T_f (quadratic)

then plug in above to find P

* to be more accurate in this question, we could worry about work done by the blood *