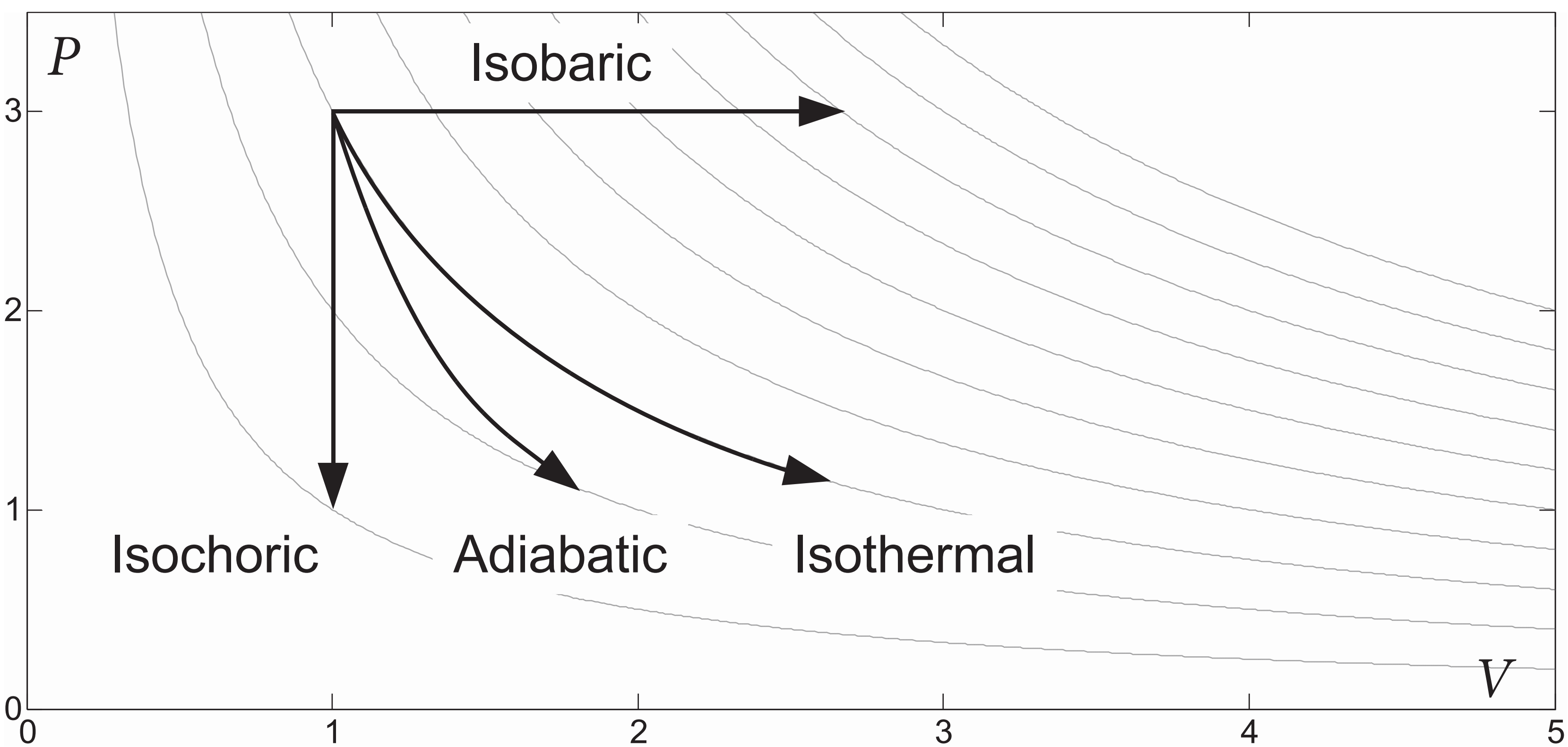
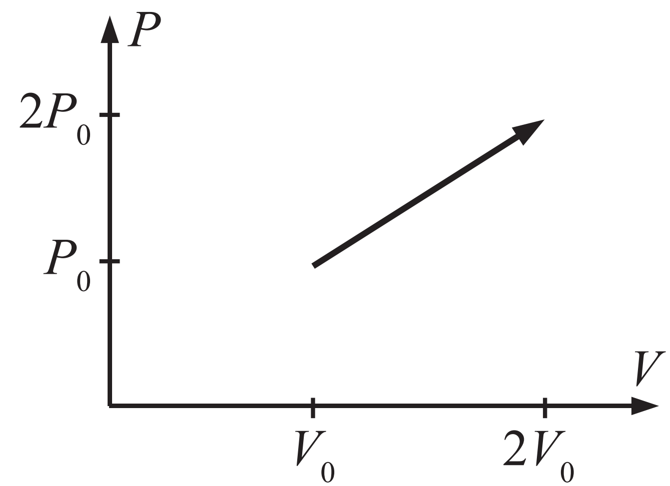
Thermodynamic Processes



One mole of an ideal monatomic gas undergoes a thermodynamic process recorded by the following PV graph. From beginning to end, both volume and pressure double from their initial values V_0 and P_0. How much work is done *by* the gas?



A. $+0.5\, P_0 V_0$

B. $+1.0\, P_0 V_0$

C. $+1.5\, P_0 V_0$

D. $+2.0\, P_0 V_0$

E. $+2.5\, P_0 V_0$

F. $+4.0\, P_0 V_0$

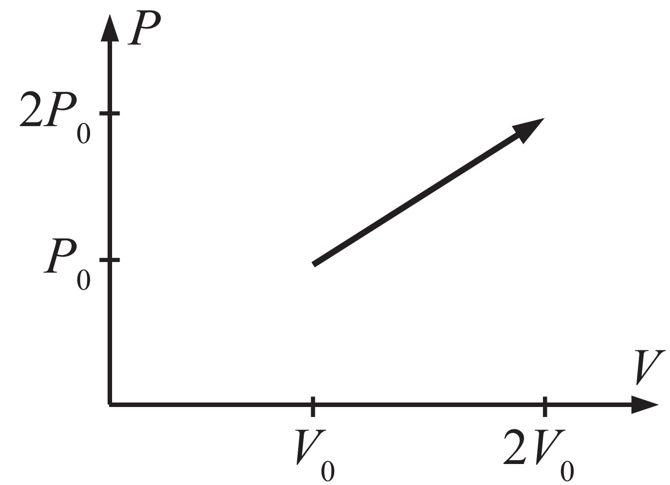
G. Other value you can determine

H. Need more information

ANS: **C**—The work done *by* the gas is $W = +1.5\, P_0 V_0$

The work done by the gas is the area under the path traced out in the PV diagram. The area is a trapezoid, or the sum of the areas of a rectangle and a triangle that you can get by simple geometry. The rectangle has an area $P_0 V_0$, while the triangle has an area $\frac{1}{2} P_0 V_0$.

One mole of an ideal monatomic gas undergoes a thermodynamic process recorded by the following PV graph. From beginning to end, both volume and pressure double from their initial values V_0 and P_0. What is the ratio of the final temperature to the initial temperature?



A. 1

B. 3

C. 4

D. 1/2

E. 1/3

F. 1/4

G. Other value you can determine

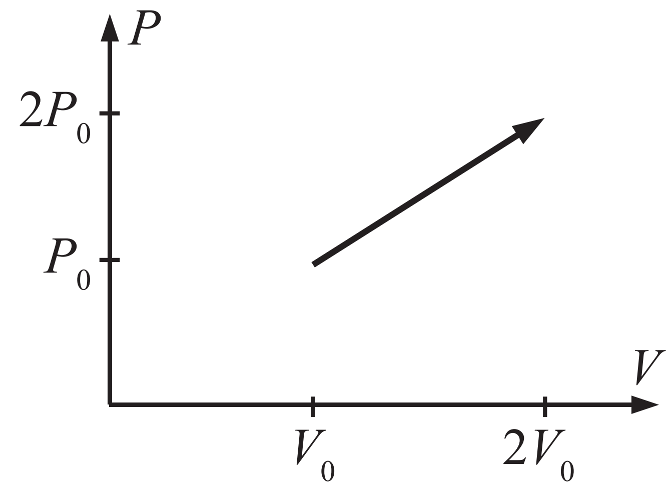
H. Need more information

ANS: C—The final temperature is 4 times greater than the initial temperature.

The temperature is determined by the product of P and V (when the amount of gas is constant). Therefore we can set up a simple ratio:

$$\frac{T_f}{T_i} = \frac{P_f V_f}{P_i V_i} = \frac{(2P_0)(2V_0)}{P_0 V_0} = 4\ .$$

One mole of an ideal monatomic gas undergoes a thermodynamic process recorded by the following PV graph. From beginning to end, both volume and pressure double from their initial values V_0 and P_0. How much does the internal (thermal) energy of the gas change?



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C. $+2.5\, P_0 V_0$

D. $+3.0\, P_0 V_0$

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F. $+9.0\, P_0 V_0$

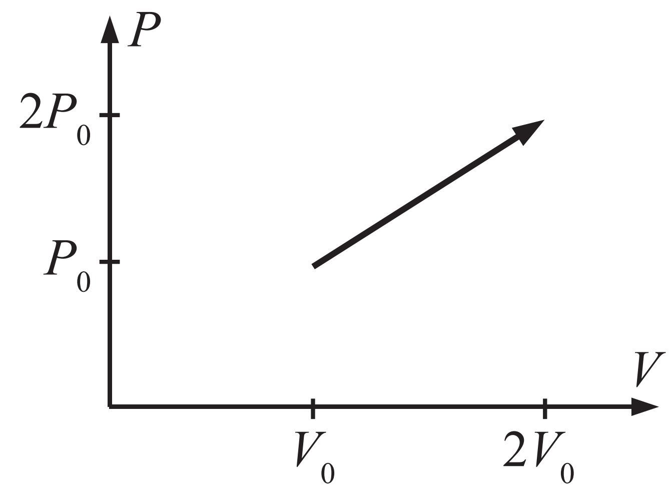
G. Other value you can determine

H. Need more information

ANS: E—The thermal energy increases by $\Delta U = +4.5\, P_0 V_0$.

Recall that the total energy of an ideal gas is $U = (f/2)PV$. Therefore, to find the internal energy at any point we just need to compute the product of pressure and volume at that point. In this case we have a monatomic gas, so $f = 3$ (all translational degrees of freedom). The initial energy is $U_i = (3/2)P_0 V_0$, while the final energy is $U_f = (3/2)(2P_0)(2V_0)$. Therefore, the change in energy is $\Delta U = +4.5 P_0 V_0$.

One mole of an ideal monatomic gas undergoes a thermodynamic process recorded by the following PV graph. From beginning to end, both volume and pressure double from their initial values V_0 and P_0. How much *heat* was added to the gas?



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F. $+7.5\,P_0 V_0$

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ANS: E—The heat added to the gas is $Q = +6.0\,P_0 V_0$.

Heat is not directly represented on a PV diagram. However, we can use the first law of thermodynamics to determine Q from the work and energy change we have already determined from the diagram: $Q = \Delta U + W = +6.0 P_0 V_0$. Think of it this way. We need to add enough heat both to raise the energy of the gas by $+4.5 P_0 V_0$ and allow it to do $+1.5 P_0 V_0$ of work on its surroundings.

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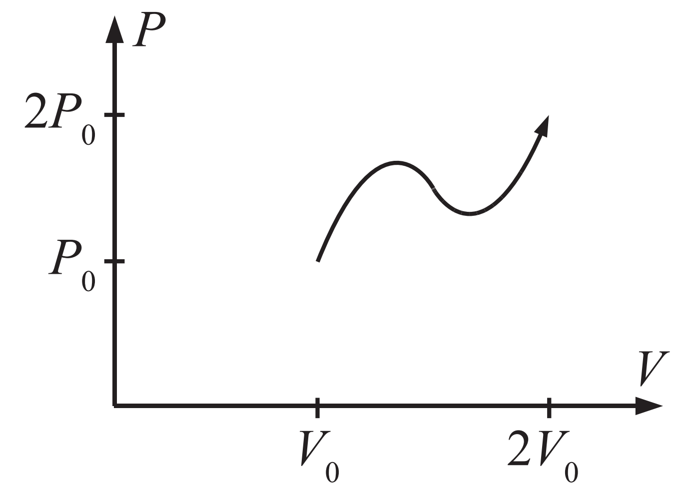

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ANS: H—We need more information.

The work done by a gas depends on the specific path of the process on a PV diagram. You may be able to get a pretty good estimate of the work done by eye with the given graph, (it looks to me like $W \approx +1.5P_0V_0$) but you cannot get the exact answer without knowing specifically how pressure changes with volume.

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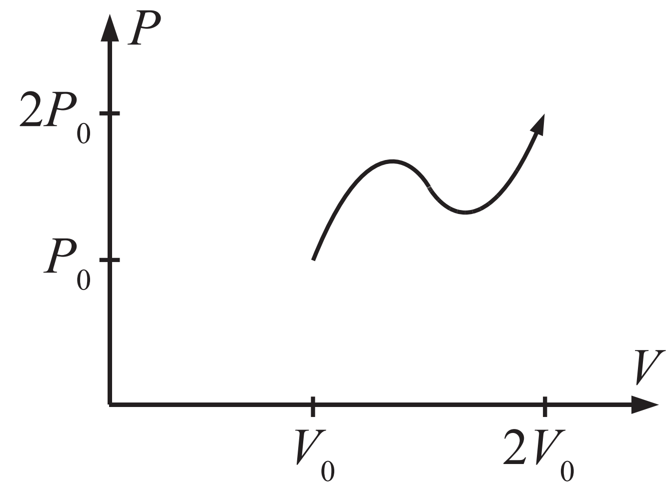

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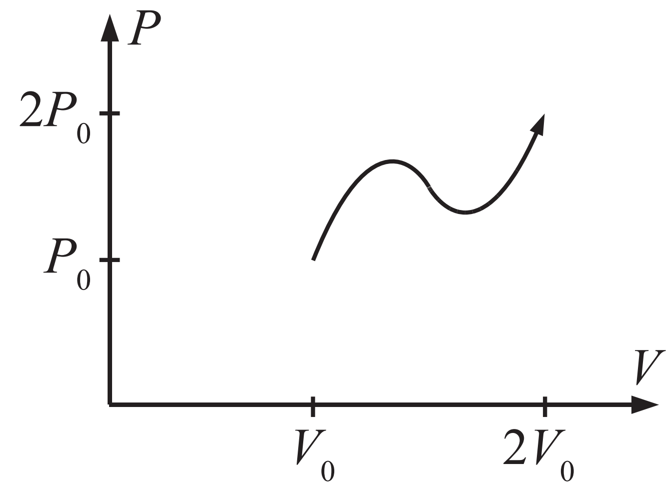

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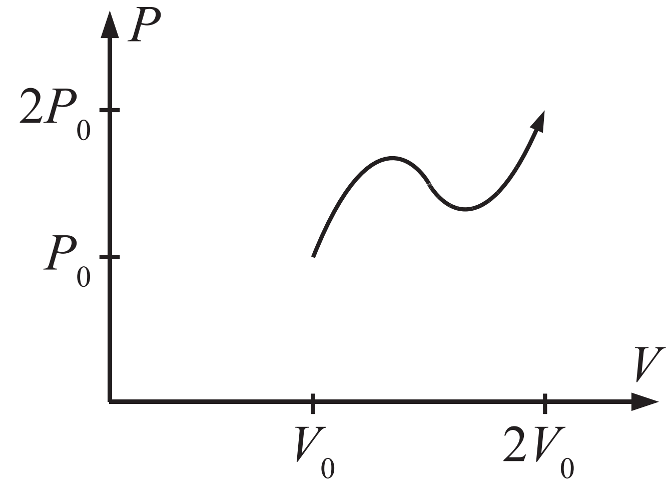

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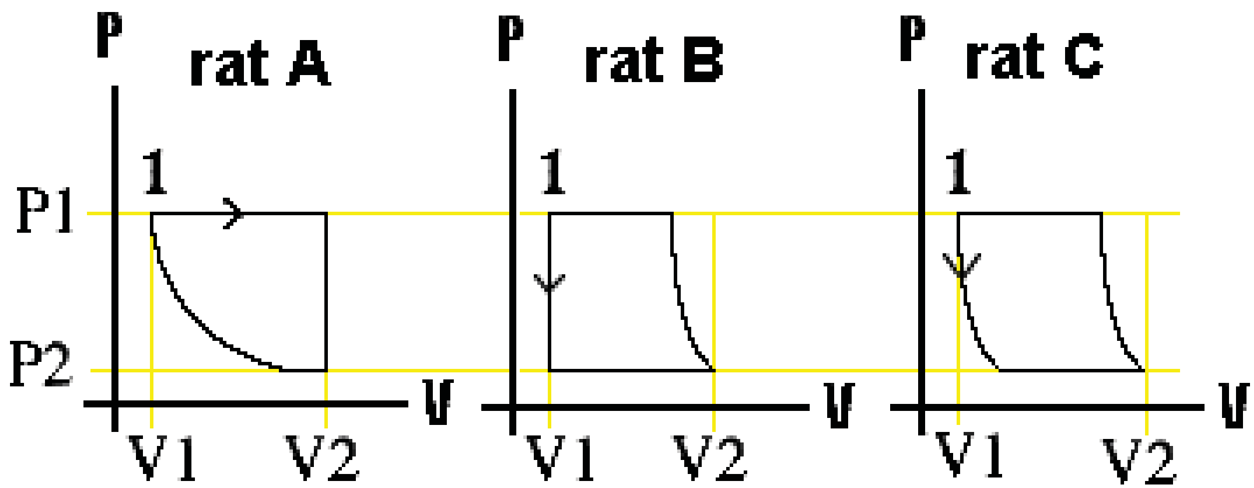
ANS: H—We need more information.

As with work, the heat added to the gas is determined by the specific path traced out in the PV diagram. We cannot determine the work done without more information, and therefore we cannot determine the heat added without more information.

Warmup Question

Three laboratory rats are placed inside three identical environmental chambers and subjected to three different cycles of changing volume and pressure. In each case, the maximum and minimum values of volume and pressure were the same. In each case, the chamber returns to its original volume and pressure at the end of the cycle. PV diagrams describing the three cycles are shown in the figure.



Which rat was subjected to the highest temperature? Explain.
Which rat was subjected to the lowest temperature? Explain.

ANS: Rat A is subjected to the highest temperature. Rat B is subjected to the lowest temperature.

The easiest way to see this is with the ideal gas law, $PV = nRT$. All gases have equal greatest and lowest values of P and V, but not necessarily simultaneously.

Gas A has greatest value of PV (in the upper-right corner of the cycle), at which point it has the highest temperature. Gas B has the lowest PV (in the lower-left corner of the cycle), at which point it has the lowest temperature.

Remember, moving to the right on a PV diagram corresponds to an increase in temperature. Moving up on a PV diagram corresponds to an increase in temperature.

Warmup Question

The readings discuss the molar heat capacity at constant pressure and the molar heat capacity at constant volume. Why have we not defined similar heat capacities to describe the other two standard processes, isothermal and adiabatic? How should you treat those processes?

ANS: The concept of heat capacity is meaningless for these processes. Heat capacity relates how the temperature of an object changes as you add heat to it. For isothermal and adiabatic processes, the heat added and the temperature change are unrelated.

For an isothermal process, the temperature never changes. If you want, you *could* say the "isothermal heat capacity" is infinite. However, that doesn't tell you anything about the specific situation because it applies to all isothermal processes. Besides, what are you going to do with an infinite heat capacity, anyway?

For an adiabatic process, the temperature changes even when no heat is added. If you want, you could say the "adiabatic heat capacity" is zero, but again, what value is that? It's the same for all adiabatic processes.

Warmup Question

You are recruited to a government position for which you are totally unqualified (a.k.a., a sinecure). What kind of jobs are you best suited for, given that you can't do the work?

A. isovolumetric

B. adiabatic

C. isobaric

D. isothermal

ANS: A—An isovolumetric (a.k.a. isochoric or isovolumic) process is one in which the system does no (mechanical) work. Punny, huh?