Thermodynamics
Study of heat and temperature

Total energy
$E = U + K + E_{int}$
U: potential energy
K: kinetic energy
E_{int}: internal or thermal energy

Temperature
Measure of kinetic energy of individual molecules.
Difference in temperature causes heat energy to be exchanged between bodies in contact.

Heat
Internal energy transferred between bodies in contact.
Temperature difference drives heat transfer.

Thermal Equilibrium
Occurs when two bodies are at the same temperature.
No heat is transferred between bodies in thermal equilibrium.

Ideal Gas Law
$P_1V_1/T_1 = P_2V_2/T_2$
P_1, P_2: initial and final pressure
V_1, V_2: initial and final volume
T_1, T_2: initial and final temperature (in Kelvin!)

Problem: Ideal Gas Law (1998)

53. The absolute temperature of a sample of monatomic ideal gas is doubled at constant volume. What effect, if any, does this have on the pressure and density of the sample of gas?

	Pressure	Density
(A)	Remains the same	Remains the same
(B)	Remains the same	Doubles
(C)	Doubles	Remains the same
(D)	Doubles	Multiplied by 4
(E)	Is multiplied by a	Multiplied by 4

Show your work:

Problem: Ideal Gas Law (1988)

23. An ideal gas in a closed container initially has volume V, pressure P. and Kelvin temperature T. If the temperature is changed to 3T. which of the following pairs of pressure and volume values is possible?

(A) 3P and V
(B) P and V
(C) P and V/3
(D) P/3 and V
(E) 3P and 3V

Show your work:

Ideal Gas Equation (form 1)
PV= nRT
P: pressure
V: volume
n: number of moles
R: gas law constant
T: temperature in Kelvin

Ideal Gas Equation (form 2)
PV= NkT
P: pressure
V: volume
N: number of molecules
k: Boltzman's constant
T: temperature in Kelvin

Ideal Gas Constant and Boltzman's Constant
$R= N_Ak$
R: ideal gas constant
8.31 J/mol K
N_A: Avagadro's number
k: Boltzman's constant
1.38×10^{-23} /mol K

Kinetic Theory of Gases
#1:Gases consist of a large number of molecules that make elastic collisions with each other and the walls of the container.
#2: Molecules are separated, on average, by large distances and exert no forces on each other except when they collide.
#3: There is no preferred position for a molecule in the container, and no preferred direction for the velocity.

Problem: Kinetic Theory (1998)

61. Which of the following statements is NOT a correct assumption of the classical model of an ideal gas?

(A) The molecules are in random motion.
(B) The volume of the molecules is negligible compared with the volume occupied by the gas.
(C) The molecules obey Newton's laws of motion.
(D) The collisions between molecules are inelastic.
(E) The only appreciable forces on the molecules are those that occur during collisions.

Explain your reasoning:

<u>Average Kinetic Energy of Molecules</u>

$K_{ave} = {}^{3}/_{2}\, k_B T$

K_{ave}: average kinetic energy (Joules)
k_B: Boltzmann's Constant (1.38×10^{-23} J/K)
T: Temperature (K)

Problem: Kinetic Theory (1998)

62. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If υ_1 is the average speed of the gas molecules before the absorption of heat and υ_2 is their average speed after the absorption of heat, what is the ratio υ_2/υ_1?

(A) $\frac{1}{2}$

(B) 1

(C) $\sqrt{2}$

(D) 2

(E) 4

Show your work:

Problem: Kinetic Theory (1988)

25. If the average kinetic energy of the molecules in an ideal gas at a temperature of 300 K is *E*, the average kinetic energy at a temperature of 600 K is

(A) $E/\sqrt{2}$
(B) E
(C) $\sqrt{2}E$
(D) 2 E
(E) 4 E

Show your work:

<u>First Law of Thermodynamics</u>

$\Delta U = Q + W$

ΔU: change in internal energy of system (gas)
Q: heat added to the system (gas)
W: work done on the system (gas)

ΔU is always zero if there is no temperature change

Problem: First Law of Thermodynamics (1998)

24. In a certain process, 400 J of heat is added to a system and the system simultaneously does 100 J of work. The change in internal energy of the system is

(A) 500 J
(B) 400 J
(C) 300 J
(D) -100 J
(E) -300 J

Show your work:

Gas State
A specific combination of pressure, temperature, and volume.

Gas Processes
Isobaric process: constant pressure
Isometric process: constant volume
Isothermal process: constant temperature
Adiabatic process: no heat absorbed or emitted

Gas Cycles
The gas changes state but winds back at the starting state.
$\Delta U = 0$ for any complete gas cycle.

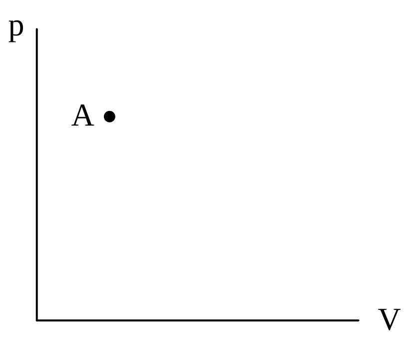
Problem: Gas processes (1988)

48. Which of the following is always a characteristic of an adiabatic process?

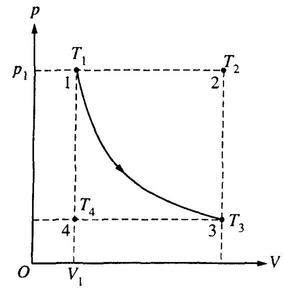
(A) The temperature does not change ($\Delta T = 0$).
(B) The pressure does not change ($\Delta P = 0$).
(C) The internal energy does not change ($\Delta U = 0$).
(D) No heat flows into or out of the system ($Q = 0$).
(E) No work is done on or by the system ($W = 0$).

Explain your reasoning:

Problem: Sketch all four processes on the graph below, beginning each process at State A on the graph.



Problem: Gas Processes (1998)

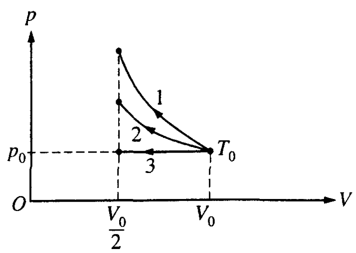


52. An ideal gas is initially in a state that corresponds to point 1 on the graph above, where it has pressure p_1, volume V_1, and temperature T_1. The gas undergoes an isothermal process represented by the curve shown, which takes it to a final state 3 at temperature T_3. If T_2 and T_4 are the temperatures the gas would have at points 2 and 4, respectively, which of the following relationships is true?

(A) $T_1 < T_3$
(B) $T_1 < T_2$
(C) $T_1 < T_4$
(D) $T_1 = T_2$
(E) $T_1 = T_4$

Explain your reasoning:

Questions 22-23



A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

Problem: Work done on a gas (1998)

22. Which of the following is true of the mechanical work done on the gas?

(A) It is greatest for process 1.
(B) It is greatest for process 3.
(C) It is the same for processes 1 and 2 and less for process 3.
(D) It is the same for processes 2 and 3 and less for process 1.
(E) It is the same for all three processes.

Explain your reasoning:

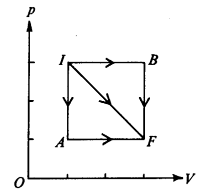
Problem: Ideal gas law (1998)

23. Which of the following is true of the final temperature of this gas?

(A) It is greatest for process 1.
(B) It is greatest for process 2.
(C) It is greatest for process 3.
(D) It is the same for processes 1 and 2.
(E) It is the same for processes 1 and 3.

Show your work:

Problem: Gas Processes (1988)



24. If three identical samples of an ideal gas are taken from initial state *I* to final state *F* along the paths *IAF*, *IF*, and *IBF* as shown in the *p V*-diagram above, which of the following must be true?

(A) The work done by the gas is the same for all three paths.
(B) The heat absorbed by the gas is the same for all three paths.
(C) The change in internal energy of the gas is the same for all three paths.
(D) The expansion along path *IF* is adiabatic.
(E) The expansion along path *IF* is isothermal.

State your reasoning:

<u>Work done BY gases</u>
Area under the curve
Positive area for expansions; negative area for compression
Arrow pointing right is positive work done by gas (and W is negative)
Arrow pointing left is negative work done by gas (and W is positive)

<u>Work done ON gases</u>
Also the area under the curve; but after finding the work done by the gas, you need to take the negative of that number.
Arrow pointing right is negative work done by environment (and W is negative)
Arrow pointing left is positive work done by environment (and W is positive)

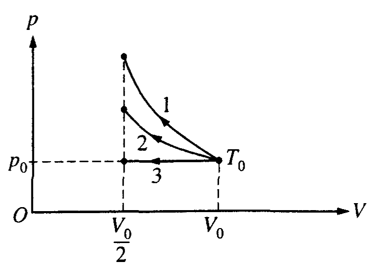
<u>Work at constant pressure</u>
$W = - p\Delta V$

Work for a full cycle
Start and end at the same spot
Work is area inside the shape defined by the steps of the cycle
Clockwise cycles
- Work done by gas is positive
- Work done by environment is negative
- W is therefore negative

Counterclockwise cycles
- Work done by gas is positive
- Work done by environment is negative
- W is therefore positive

Problem: Gas Processes (1998)

Questions 22-23



A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

22. Which of the following is true of the mechanical work done on the gas?

(F) It is greatest for process 1.
(G) It is greatest for process 3.
(H) It is the same for processes I and 2 and less for process 3.
(I) It is the same for processes 2 and 3 and less for process 1.
(J) It is the same for all three processes.

Explain your reasoning:

23. Which of the following is true of the final temperature of this gas?

(F) It is greatest for process 1.
(G) It is greatest for process 2.
(H) It is greatest for process 3.
(I) It is the same for processes 1 and 2.
(J) It is the same for processes 1 and 3.

Explain your reasoning:

Specific Heat of gases
$Q = n C_p \Delta T$
- Q: heat absorbed by gas
- n: number of moles of gas
- C_p: constant pressure specific heat (5/2 R)
- ΔT: change in temperature (K or Celsius)

$Q = \Delta U_{int} = n C_v \Delta T$
- Q: heat absorbed by gas
- n: number of moles of gas
- C_v: constant volume specific heat (3/2 R)
- ΔT: change in temperature (K or Celsius)

Second Law of Thermodynamics
No process is possible whose sole result is the complete conversion of heat from a hot reservoir into mechanical work.
No process is possible whose sole result is the transfer of heat from a cooler to a hotter body.

Heat Engines
As heat is transferred from a hot reservoir to a cold reservoir, the heat engine converts some of this heat into mechanical work. It can never convert 100% to mechanical work however.

Efficiency of Heat Engine
Efficiency = $W/Q_H = (Q_H - Q_C)/Q_H$

Carnot Engine
The most efficient heat engine theoretically possible. No one has built a Carnot engine. In addition to the efficiency equations shown above, Carnot efficiency can be calculated from the temperatures of the hot and cold reservoirs.

Carnot Efficiency
Efficiency = $(T_H - T_C)/T_H$

Problem: Efficiency (1993)

55. In each cycle of a Carnot engine, 100 joules of heat is absorbed from the high-temperature reservoir and 60 joules is exhausted to the low-temperature reservoir. What is the efficiency of the engine?

(A) 40 %
(B) 60 %
(C) 67 %
(D) l50 %
(E) l67 %

Show your work:

Entropy
Disorder
Entropy in the universe tends to spontaneously increase
A system must expend energy to counteract this tendency of entropy to increase.

<< ADVANCED TOPIC>>
Entropy
$\Delta S = Q/T$

ΔS: Change in entropy (J/K)
Q: Heat going into system (J)
T: Kelvin temperature (K)