A. Heat, Heat Transfer, Temperature, Calorimetry (Q, T) — Step 1: Topics

B. PV = nRT = NkT, Eq. of State, Microscopic Properties, Equipartition (A-D)

C. 1st Law, Work, pV diagrams & processes

D. 2nd Law & Entropy, Heat engines

Step 2: formulae

Step 3: E, M, H?

University of California, San Diego

UCSD: Spring 2022

Practice Thermodynamics Problems

May 16, 2022

Topics: C

Difficulty: M

Equations: PV = nRT

1. A gas is initially at temperature T_0 and pressure P_0. If the gas undergoes an isothermal expansion to twice its initial volume, what are the final temperature and pressure of the gas?

A) Temperature T_0 and pressure P_0.
B) Temperature $2T_0$ and pressure P_0.
C) Temperature T_0 and pressure $(1/2)P_0$.
D) Temperature $(1/2)T_0$ and pressure $(1/2)P_0$.
E) Temperature T_0 and pressure $2P_0$.

$\frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$

B

M

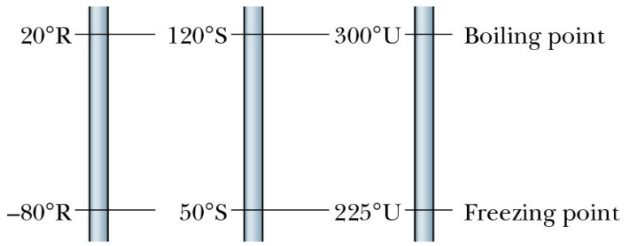
2. You have a balloon at room temperature containing air (nitrogen gas N_2 and oxygen gas O_2). An oxygen molecule has more mass than a nitrogen molecule. Which of the following statements is true of the nitrogen and oxygen molecules?

A) The oxygen molecules are moving faster than the nitrogen molecules, and both are rotating.
B) The oxygen molecules are moving slower than the nitrogen molecules, and both are rotating.
C) The oxygen molecules are moving the same speed as than the nitrogen molecules, and both are rotating.
D) The oxygen molecules are moving the same speed as the nitrogen molecules, but neither are rotating.
E) The oxygen molecules are moving slower than the nitrogen molecules, but neither are rotating.

A

M

3. The figure below shows where the freezing and boiling points of carbon dioxide are on three different temperature scales. A temperature of 450°U equals which of the following?



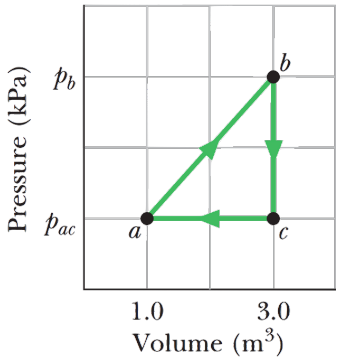
A) 140°R
B) 190°R
C) 220°S
D) 190°S
E) 220°R

C, D

4. A sample of an ideal gas is taken through the cyclic process abca shown in the figure below ($abca$). The pressures satisfy $p_b = 3p_{ac}$. Which is the following is TRUE concerning this cycle?

$W_{by} = \int_i^f p\,dV$ $\quad \Delta S = \int_i^f \frac{dQ}{T}$

$\Delta U = \frac{f}{2} nR\Delta T$ $\quad Q = nC_{P,V}\Delta T$



A) Positive work is done by the gas during ca.
B) The internal energy change of the gas is positive for bc
C) The temperature of the gas increases from c to a.
D) The entropy of the gas is highest at state b.
E) The heats extracted from the gas during bc and ca are equal.

H

C

5. Three identical gas-cylinder systems expand from the same initial state to final states that have the same volume. One system expands isothermally, one adiabatically, and one isobarically. The _____ process has the most heat added to the gas and the _____ process has the least heat added.

A) Isothermal, Isobaric.
B) Isothermal, Adiabatic.
C) Adiabatic, Isothermal.
D) Adiabatic, Isobaric.
E) Isobaric, Adiabatic.

M

$PV = nRT$

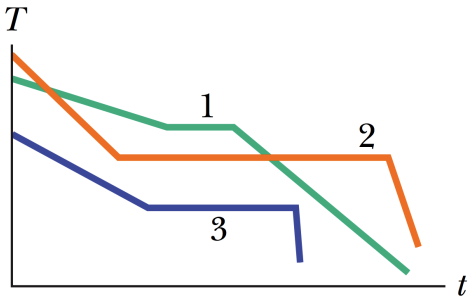
$PV^{\gamma} = \text{const.}$

A

6. Three different materials of identical mass are placed one at a time in a special freezer that can extract energy from a material at a certain constant rate. During the cooling process, each material begins in the liquid state and ends in the solid state; The figure below shows the temperature T versus time t. Rank materials 1, 2, and 3 according to specific heat in the liquid state, greatest first.

$Q = mc\Delta T$

$Q = mL$



A) 1, 2, 3
B) 3, 2, 1
C) 2, 3, 1
D) 3, 1, 2
E) 1, 3, 2

E - M

A

7. In an effort to reduce the amount of heat escaping your house in the winter, you insulate the thick walls of your house. The walls, previously filled with air (thermal conductivity $0.026\,\mathrm{W/(m\cdot K)}$), are filled with glass wool / "fiberglass" (thermal conductivity $0.048\,\mathrm{W/(m\cdot K)}$). In doing so, you _____ the heat transfer via convection and _____ heat transfer via conduction.

E-M

A) Increase, Increase
B) Decrease, Decrease
C) Increase, Decrease
D) Decrease, Increase
E) No change in either (insulation is for radiation only).

$$P_{cond} = \frac{kA\,\Delta T}{\Delta x}$$

B

8. Two containers are at the same temperature. The first contains gas with pressure p_1, molecular mass m_1, and rms speed v_{rms}. The second contains gas with pressure $3p_1$, molecular mass m_2, and average speed $2v_{\mathrm{rms}}$. What is the mass ratio m_2/m_1?

M

A) 1/4
B) 1/3
C) 2
D) 3
E) 4

$$PV = nRT$$

$$\tfrac{1}{2}mv_{rms}^2 = \tfrac{3}{2}kT$$

C

9. Does the internal energy of an ideal gas increase, decrease, or stay the same during: (i) a decrease in pressure at constant volume, (ii) an adiabatic expansion, and (iii) an increase in pressure at constant temperature?

M

A) (i) stay the same ; (ii) increase ; (iii) increase
B) (i) decrease ; (ii) decrease ; (iii) stay the same
C) (i) decrease ; (ii) decrease ; (iii) increase
D) (i) increase ; (ii) decrease ; (iii) decrease
E) (i) decrease ; (ii) stay the same ; (iii) stay the same

$$U = U(T)$$

B, C

10. A diatomic gas has rotational degrees of freedom excited, but no vibrational modes excited. How much energy in the form of heat is required to raise the temperature of 1 mol of the gas by 100 Kelvin when heating the gas at constant pressure?

M-H

A) 1.2 kJ
B) 2.1 kJ
C) 2.9 kJ
D) 3.7 kJ
E) Impossible to tell (requires the molar mass).

$$Q = nC_p\Delta T$$

$$C_v = \frac{f}{2}R \quad \text{and} \quad C_p = C_v + R$$

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11. Which of the following is NOT true regarding irreversible processes?

A) These processes lead to an increase in entropy of the universe.
B) The path of an irreversible process cannot be traced on a PV diagram.
C) Melting an ice cube in a cup of room temperature water is an example of this kind of process.
D) Macroscopic quantities like temperature and pressure are not defined for the initial and final states of a system undergoing an irreversible process.
E) Any heat transfer through a positive, finite temperature difference is an example of an irreversible process.

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12. A gas initially at temperature T_0 and pressure P_0 undergoes an adiabatic compression to half of its initial volume. What happens to the temperature and pressure of the gas?

A) The pressure increases to a value $P_f > 2P_0$ and the temperature increases.
B) The pressure increases to a value $P_f < 2P_0$ and the temperature increases.
C) The pressure decreases and the temperature increases.
D) The pressure increases to a value $P_f < 2P_0$ and the temperature decreases.
E) The pressure decreases and the temperature decreases.

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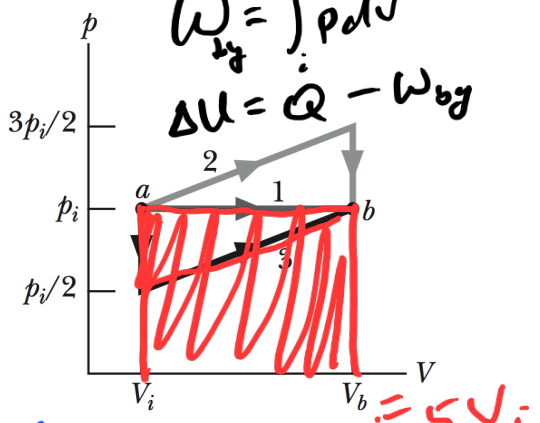
13. Shown below are three processes: 1, 2, and 3. All three processes have the same starting point, a, and the same final point, b. $V_b = 5V_i$, and the heat added to the gas in process 1 is $10p_iV_i$. What is the change in internal energy the gas undergoes in process 3?



A) $2\,p_iV_i$
B) $4\,p_iV_i$
C) $6\,p_iV_i$
D) $8\,p_iV_i$
E) $10\,p_iV_i$

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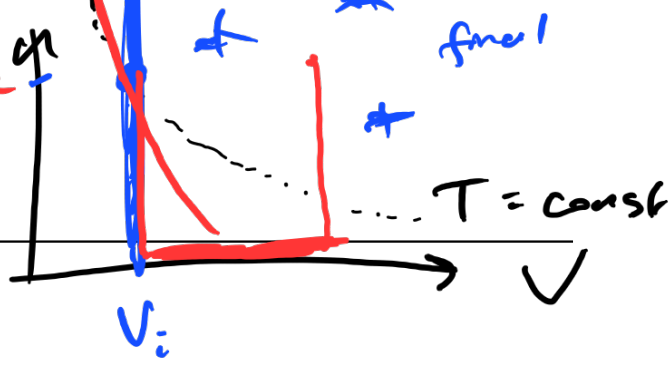
14. A gas expands and the average internal energy of the gas increases. Which of the following is not necessarily true?

A) Heat is added to the gas.
B) The gas does work on its surroundings.
C) The entropy of the gas increases.
D) The temperature of the gas increases.
E) All of the above are necessarily true.



C

15. Three identical gas-cylinder systems expand from the same initial state to final states that have the same volume. One system expands isothermally, one adiabatically, and one isobarically. The _____ process does the most work and the _____ process does the least work.

E-M

A) Isothermal, Isobaric.
B) Isothermal, Adiabatic.
C) Adiabatic, Isothermal.
D) Adiabatic, Isobaric.
E) Isobaric, Adiabatic.

$W_{by} = \int p\,dV$

A, D

16. Suppose I throw a copper block at 80°C into water at 10°C, and the two come to equilibrium. The entropy of the block has _____, the entropy of the water has _____, and the overall entropy _____.

E-M

A) Increased, Decreased, Remained Constant.
B) Increased, Decreased, Increased.
C) Decreased, Increased, Increased.
D) Increased, Increased, Increased.
E) Decreased, Increased, Remained Constant.

$Q_A + Q_B = 0$

D

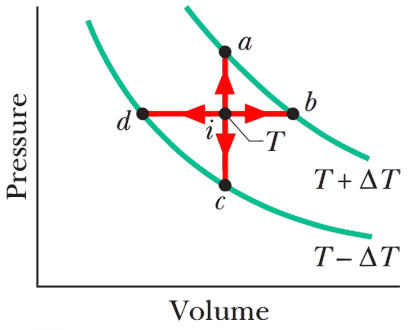
17. Point i in the figure below represents the initial state of an ideal gas at temperature T. Taking algebraic signs into account, rank the entropy changes that the gas undergoes as it moves, successively and reversibly, from point i to points a, b, c, and d, greatest first.

M-H

$\Delta S = \int \frac{dQ}{T}$

$dQ = n C_{p,v}\, dT$

A) a, b, d, c
B) c, d, b, a
C) b, a, c, d
D) d, c, a, b
E) b, a, d, c



End of Multiple Choice Questions

Topic A

$Q = mc\Delta T \qquad Q = mL$

$Q_A + Q_B = 0$

$P_{cond} = \frac{kA\Delta T}{\Delta x}$

Topic B

$PV = nRT = NkT$

$\frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$

$U_{tot} = \frac{f}{2}NkT$

Topic C

$W_{by} = \int_i^f P\,dV$

$\Delta U = Q - W_{by}$

$Q = nC_{P,V}\Delta T$

$C_V = \frac{f}{2}R \;;\; C_P = C_V + R$

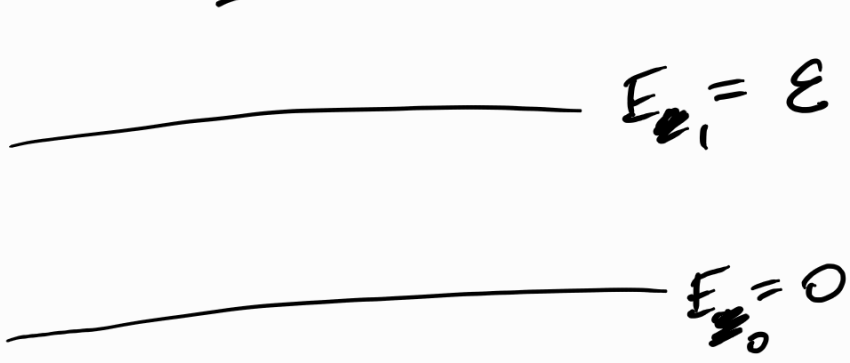
$PV^{\gamma} = \text{const.}, \quad \gamma = \frac{C_P}{C_V}$

Topic D

$\Delta S = \int_i^f \frac{dQ}{T}$

$S = k_B \ln \Omega$

Intro to Stat. Mech.



Definitely have N particles, definitely have a equilibrium temperature T.

$T = 0$ (if T zero),

$$\langle n_0 \rangle = N$$

$$\langle n_1 \rangle = 0$$

$T = \infty$

$$\langle n_0 \rangle = \frac{1}{2} N$$

$$\langle n_1 \rangle = \frac{1}{2} N$$

$T =$ finite

$$\langle n_0 \rangle = ?$$

$$\langle n_1 \rangle = ?$$

PARTITION FUNCTION

$$\mathcal{Z} = \sum_{\text{All energy states } i} g_i e^{-E_i/kT}$$

$$\mathcal{Z} = e^{-\frac{E_0}{kT}} + e^{-\frac{E_1}{kT}}$$

$$= e^{-0} + e^{-\frac{\varepsilon}{kT}} = \boxed{1 + e^{-\frac{\varepsilon}{kT}}}$$

$$\langle n_0 \rangle = N\left(\frac{e^{-E_0/kT}}{\mathcal{Z}}\right) = N\left[\frac{1}{1 + e^{-\varepsilon/kT}}\right]$$

$$\langle n_1 \rangle = N\left[\frac{e^{-\varepsilon/kT}}{1 + e^{-\varepsilon/kT}}\right]$$