General Physics I Exam 5 - Chs. 13,14,15 - Heat, Kinetic Theory, Thermodynamics Dec. 15, 2009

Name Rec. Instr. Rec. Time

For full credit, make your work clear to the grader. Show the formulas used, essential steps and results with correct units and significant figures. Partial credit is available if your work is clear. Points shown in parenthesis. For multiple choice questions, choose the *best* answer.

g = 9.80 m/s^2, 1 atm = 101.3 kPa, 1 L=10^{-3} m^3, 1 cal=4.186 J, 1 u=1.6605×10^{-27} kg, $N_A = 6.02 \times 10^{23}$/mol, $R = 8.314$ J/mol·K, $k = 1.38 \times 10^{-23}$ J/K, $\sigma = 5.67 \times 10^{-8}$ W/m^2· K^4.

Prefixes: f=10^{-15}, p=10^{-12}, n=10^{-9}, $\mu = 10^{-6}$, m=10^{-3}, c=10^{-2}, k=10^3, M=10^6, G=10^9, T=10^{12}, P=10^{15}.

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1. (2) In solid metals such as iron, copper, nickel, about how far apart are neighboring atoms?

   a. 0.2 mm b. 0.2 μm c. 0.2 nm d. 0.2 pm

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2. (2) A temperature change of 1.0 °C is equivalent to what temperature change in Fahrenheit?

   a. 0.56 °F b. 1.0 °F c. 1.8 °F d. 32 °F e. 212 °F.

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3. (2) In the Periodic Table, the "mass number" is 39.9 for argon. This means that

   a. 39.9 argon atoms have a mass of 1u. b. 1 argon atom has a mass of 39.9u.
   c. 39.9 argon atoms have a mass of 1g. d. 1 argon atom has a mass of 39.9g.

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4. (2) In a 1-**mole** sample of these elements, which has the least number of atoms?

   a. carbon (C) b. argon (Ar) c. gold (Au) d. all have the same number.

5. (2) In a 1-**gram** sample of these elements, which has the least number of atoms?

   a. carbon (C) b. argon (Ar) c. gold (Au) d. all have the same number.

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6. (4) Some substances that behave as ideal gases at room temperature and 1 atm pressure are helium (He), argon (Ar), methane (CH_4) and carbon dioxide (CO_2).

a) (2) Which, as a pure gas, has the **highest density** at room temperature and 1 atm pressure?

   a. He b. Ar c. CH_4 d. CO_2 e. all tie.

b) (2) Which, as a pure gas, has the greatest **number of molecules** in any cubic millimeter?

   a. He b. Ar c. CH_4 d. CO_2 e. all tie.

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7. (14) A helium tank has an internal volume of 50.0 L. It is filled with 2.00 kg of pure helium gas. Just after filling, the gas temperature is 47.0 °C. Treat the gas as ideal.

a) (5) Find the pressure inside the tank, in atmospheres.

b) (5) Find the density of the gas inside the tank.

The tank cools off to -13.0 °C after being left outside, but its internal volume is still 50.0 L.

c) (2) This caused the pressure inside the tank to a. decrease. b. increase. c. stay the same.

d) (2) This caused the density of the gas inside the tank to a. decrease. b. increase. c. stay the same.

8. (10) There are small amounts of helium (He), argon (Ar), methane (CH_4) and carbon dioxide (CO_2) in the air you are now breathing. Assume that the pressure in the air is 1.00 atm and the temperature is 22.0 °C.

a) (2) Which of these molecules has the highest average translational kinetic energy?

a. He b. Ar c. CH_4 d. CO_2 e. all tie.

b) (2) Which of these molecules has the highest root-mean-square speed?

a. He b. Ar c. CH_4 d. CO_2 e. all tie.

c) (2) Which quantity **does not** directly affect the rms speed of molecules?

a. their mass. b. the temperature. c. the pressure.

d) (4) Find the rms speed for the carbon dioxide molecules.

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9. (2) When a mass m of ice melts and becomes liquid water,

a. the ice absorbs latent heat. b. the ice gives out latent heat. c. the ice does not exchange any heat.

10. (2) The specific heat of water is 1.00 cal/g·C°, and the specific heat of copper is 0.093 cal/g·C°. If you have a 1.00 kg sample of each, which one needs to absorb more heat to change its temperature by 1.00 °C?

a. the 1.00 kg of water b. the 1.00 kg of copper c. it's a tie.

11. (2) **T** **F** A liter of water at 4.0 °C has less mass than a liter of water at 8.0 °C.

12. (2) **T** **F** A kilogram of water at 4.0 °C has less internal energy than a kilogram of water at 8.0 °C.

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13. (10) A 44-gram bullet moving at 420 m/s is fired into a container holding 1.0 L water. The bullet comes to rest in the water. 95% of its kinetic energy becomes heat transferred into the water (the remaining 5% heats the bullet).

a) (5) How much heat, in calories, does the water receive?

b) (5) What temperature change does the water experience?

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14. (4) A balloon contains 8.0 grams of helium (ideal gas) initially at 1.00 atm pressure and 22.0 °C. If the temperature of the gas is raised to 32.0 °C at constant pressure, what change in internal energy does the gas experience?

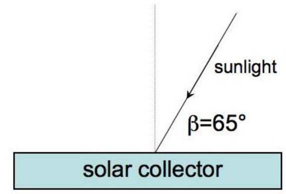
15. (10) A 0.25-kg iron mass initially at 0.0 °C is dropped into a large container of liquid nitrogen at 77 K, causing gaseous nitrogen to emerge. The specific heat of iron is 0.45 kJ/kg·C° and the latent heat of vaporization of nitrogen is 2.00×10^2 kJ/kg.

a) (5) After the iron cools to 77 K, how much heat, in kilo-joules, did it give to the nitrogen?

b) (5) What total mass of nitrogen was vaporized?

16. (6) A tungsten sphere (emissivity $e = 0.350$) of radius 2.00 cm is losing heat by radiation at a **net rate** of 3.00 watts, while surrounded by an environment at 295 K. What is the temperature of the sphere's surface?

17. (12) A solar hot water heater has a collector of size 2.0 m × 1.5 m and emissivity $e = 0.80$ set so the sun's rays make an angle of $\beta = 65°$ relative to the collector surface. It is operating on a day when the incident solar radiation has an intensity of 950 W/m^2.



a) (6) What total solar power is the collector **absorbing** from the sunlight?

a) (6) What is the minimum time needed for the collector to heat 1.0×10^2 liters of water from 20.0 °C to 80.0 °C? (Assume the sun's angle does not change.)

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18. (6) 4.5 moles of ideal gas expands **isothermally**, doing 1200 J of work on its surroundings.

a) (2) The temperature of the gas a. decreased. b. increased. c. did not change.

b) (2) The change in internal energy of the gas is a. negative. b. positive. c. zero.

c) (2) The heat added to the gas is a. less than 1200 J. b. 1200 J. c. more than 1200 J.

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19. (6) 1.5 moles of ideal gas expands **adiabatically**, doing 450 J of work on its surroundings.

a) (2) The temperature of the gas a. decreased. b. increased. c. did not change.

b) (2) The change in internal energy of the gas is a. negative. b. positive. c. zero.

c) (2) The heat added to the gas is a. less than 450 J. b. 450 J. c. more than 450 J.

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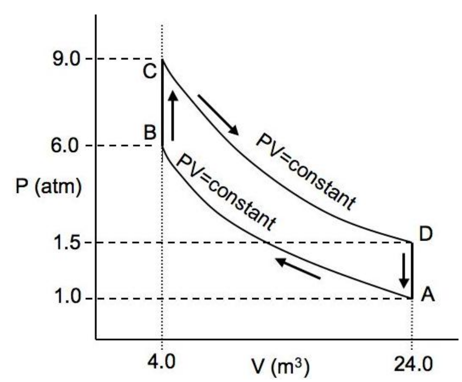
20. (10) The PV diagram shows a sequence of processes (AB, BC, etc.) applied to an ideal gas inside an engine.



a) (2) Which process is an isothermal compression?

a. AB b. BC c. CD d. DA e. there isn't one.

b) (2) In which process does the pressure increase at constant volume?

a. AB b. BC c. CD d. DA e. there isn't one.

c) (2) In which process is work done **on the gas**?

a. AB b. BC c. CD d. DA e. there isn't one.

d) (4) Find the work done **by the gas** in the process DA.

21. (10) An engine burns fuel at a temperature of 750 K and releases exhaust heat at a temperature of 450 K. The rate at which energy is released from burning fuel is 85 kW.

a) (5) What is the maximum possible efficiency for this engine?

b) (5) Calculate the maximum possible mechanical power output for this engine.

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22. (14) A freezer keeps food at -14 °C while exhausting heat into a room at +24 °C. During 5.0 minutes of operation, the freezer extracts 32 kJ of heat from the food, while exhausting 42 kJ of heat into the room.

a) (5) Calculate the actual coefficient of the performance of the freezer.

b) (5) What is the average (electrical or mechanical) power input to the freezer?

c) (4) If the freezer operated between the same temperatures using a Carnot cycle, what would its coefficient of performance be?

Chapter 15 Equations

First Law of Thermodynamics (U = internal energy):

$\Delta U = Q - W$ or $\Delta KE + \Delta PE + \Delta U = Q - W$

work = W = area under $P(V)$ curve. $W = P\Delta V$ for isobaric processes.

heat = Q = heat absorbed by the system. $Q = 0$ for adiabatic processes.

Heat Engines:

$W = Q_H - Q_L$, efficiency $e = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$, $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$ for ideal Carnot cycle.

Cooling Machines, Heat Pumps:

$W = Q_H - Q_L$, refrigerators: COP $= \frac{Q_L}{W}$, heat pumps: COP $= \frac{Q_H}{W}$, $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$ for ideal Carnot.

Power:

$P_{\text{ave}} = \frac{W}{t}$, or use $P_{\text{ave}} = \frac{\text{energy}}{\text{time}}$.

Chapter 14 Equations

Internal Energy:

$U = \frac{3}{2}Nk_BT = \frac{3}{2}nRT$, for ideal monatomic gases.

Mechanical Equivalent of Heat, Specific Heat, Latent Heat:

1 cal = 4.186 J, $Q = mc\Delta T$, $Q = mL_F$, $Q = mL_V$.

For water, c = 1.00 cal/g·C° = 4.186 kJ/kg ·C°, c_{ice} = 0.50 cal/g·C° = 2.1 kJ/kg ·C°.

L_F = 79.7 kcal/kg = 333 kJ/kg, L_V = 539 kcal/kg = 2260 kJ/kg.

Heat Transfer:

Conduction: $P = \frac{Q}{t} = kA\frac{\Delta T}{l}$.

Radiation: $P = \frac{\Delta Q}{\Delta t} = e\sigma AT^4$, $P = \frac{\Delta Q}{\Delta t} = e\sigma A(T_1^4 - T_2^4)$, $\sigma = 5.67 \times 10^{-8}$ W/m²· K⁴.

Solar Energy: $P = \frac{\Delta Q}{\Delta t} \approx (1000 \text{ W/m}^2)\, eA\cos\theta$

Chapter 13 Equations

Atomic Theory & Moles:

$n = \frac{N}{N_A}$, $n = \frac{m}{M_A}$, $N_A = 6.022 \times 10^{23}$/mol, $1 \text{ u} = \frac{1 \text{ gram}}{N_A} = 1.6605 \times 10^{-27}$ kg.

Temperature scales:

T(°C) = $\frac{5}{9}$[T(°F)-32], T(°F)=$\frac{9}{5}$ T(°C)+32, T(K)=T(°C)+273.15

Thermal Expansion:

$\Delta L = \alpha L_0 \Delta T$, $\Delta V = \beta V_0 \Delta T$.

Ideal Gas Law:

$PV = nRT$, or $PV = Nk_BT$, R = 8.314 J/mol·K, $k_B = \frac{R}{N_A} = 1.38 \times 10^{-23}$ J/K.

Kinetic Theory:

$\bar{\text{KE}} = \frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}k_BT$, $v_{\text{rms}} = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3RT}{M_A}}$, $m = M_A/N_A$.

Pressure Units:

1 Pa = 1 N/m², 1 bar = 10^5 Pa = 100 kPa, 1 mm-Hg = 133.3 Pa.

1.00 atm = 101.3 kPa = 1.013 bar = 760 torr = 760 mm-Hg =14.7 lb/in².

(over)

Some Elemental Properties

symbol	element	atomic number	mass number
H	hydrogen	1	1.00794
He	helium	2	4.00260
C	carbon	6	12.0107
N	nitrogen	7	14.0067
O	oxygen	8	15.9994
Ne	neon	10	20.180
Ar	argon	18	39.948
Fe	iron	26	55.845
Ni	nickel	28	58.693
Cu	copper	29	63.546
Au	gold	79	196.97
U	uranium	92	238.03

Mass numbers are atomic masses in units of "u" where 1 u $= 1.6605 \times 10^{-27}$ kg,
or, molar masses for the element (1 mole $= 6.02 \times 10^{23}$ atoms), measured in grams.
($N_A \times 1$ u = 1 gram)

Energy, Force, Power

Work & Kinetic & Potential Energies:

$W = Fd\cos\theta$, $\quad \mathrm{KE} = \frac{1}{2}mv^2$, $\quad \mathrm{PE}_{\mathrm{gravity}} = mgy$, $\quad F_{\mathrm{gravity}} = -mg$. $\quad \mathrm{PE}_{\mathrm{spring}} = \frac{1}{2}kx^2$, $\quad F_{\mathrm{spring}} = -kx$.

Conservation or Transformation of Energy:

"work-KE theorem" $\Delta\mathrm{KE} = W_{\mathrm{net}}$, **or use conservation law**: $\Delta\mathrm{KE} + \Delta\mathrm{PE} = W_{\mathrm{NC}}$. $\quad E_2 = E_1 + W_{\mathrm{NC}}$.

Power:

$P_{\mathrm{ave}} = \frac{W}{t}$, $\quad$ or use $P_{\mathrm{ave}} = \frac{\mathrm{energy}}{\mathrm{time}}$.

Trig summary

$\sin\theta = \frac{(\mathrm{opp})}{(\mathrm{hyp})}$, $\quad \cos\theta = \frac{(\mathrm{adj})}{(\mathrm{hyp})}$, $\quad \tan\theta = \frac{(\mathrm{opp})}{(\mathrm{adj})}$, $\quad (\mathrm{opp})^2 + (\mathrm{adj})^2 = (\mathrm{hyp})^2$.

$\sin\theta = \sin(180^\circ - \theta)$, $\quad \cos\theta = \cos(-\theta)$, $\quad \tan\theta = \tan(180^\circ + \theta)$, $\quad \sin^2\theta + \cos^2\theta = 1$.