Physics 2010-004

Name: SOLUTION KEY

Final (A) – 16 December 2009

Part A: Hard Multiple Choice (20 points total, 2 points each). Circle the best answer.

1. Which of the following best describes absolute zero?

a) 0°C b) 0°F c) −890°F (d) −273°C e) -32 K

2. A blackbody is measured to have a thermal energy of 6.13×10^{-21} J. What is its temperature?

a) 273°C b) −460°F c) 5770°C d) 1380 K (e) 296 K

$TE = \frac{3}{2} k_B T$, $T = \frac{2\,TE}{3 k_B} = \frac{2(6.13 \times 10^{-21} J)}{3(1.381 \times 10^{-23} J/K)} = 296 K$

3. 2.02 cubic meters of a gas is at a pressure of 3.45×10^5 Pa with an internal energy of 2.34×10^6 J. What is the enthalpy of this gas?

(a) 3.04×10^6 J b) 1.64×10^6 J c) 3.36 J

d) 1.71×10^5 N e) 6.97×10^5 N

$H = U + PV$
$= 2.34 \times 10^6 J + (3.45 \times 10^5 Pa)(2.02 m^3)$
$= 3.04 \times 10^6 J$

4. $\vec{A}_y$ has a length of 0.32 m. If $\theta = 46°$, what is the length of $\vec{A}$? $A = \frac{A_y}{\sin\theta} = \frac{0.32 m}{\sin 46°} = 0.44 m$

a) 320 mm b) 0.22 m c) 0.52 cm (d) 44 cm e) 0.34 m

5. At its hottest, an ideal engine is at a temperature 1200 K and at its coolest, a temperature of 360 K. What is the efficiency of this engine?

a) 0.50 (b) 0.70 c) 0.12 d) 0.20 e) 0.42

$e = 1 - \frac{T_C}{T_H} = 1 - \frac{360 K}{1200 K} = 0.70$

6. An external force of 52.2 N is imparted on an object which causes it to accelerate at a rate of g. What is the mass of the object?

(a) 5330 gm b) 522 gm c) 2.74 kg d) 0.174 kg e) 7.74 kg

$F = mg$, $m = \frac{F}{g} = \frac{52.2 N}{9.80 m/s^2} = 5.33 kg$

7. An ideal gas has a particle density of 2.34×10^{25} particles/m^3 and temperature of 342 K. What is the pressure of this gas?

a) 8.00×10^{27} Pa   b) 1.09 atm   c) 1.01×10^5 Pa

d) 4.45 Pa   e) 342 atm

$P = n k_B T = (2.34\times10^{25}\,m^{-3})(1.381\times10^{-23}\,J/K)(342\,K) = 1.11\times10^5\,Pa = 1.09\,atm$

8. The Earth rotational angular momentum is 7.08×10^{33} J·s and has an angular speed of 7.27×10^{-5} rad/s. What is the moment of inertia of the Earth as it spins about its axis?

a) 9.74×10^{37} kg m^2 b) 1.34×10^{47} kg m^2 c) 6.38×10^6 kg m^2

d) 5.98×10^{24} kg m^2 e) 7.10×10^4 kg m^2

$L = I\omega, \quad I = \frac{L}{\omega} = \frac{7.08\times10^{33}\,J s}{7.27\times10^{-5}\,rad/s} = 9.74\times10^{37}\,kg\,m^2$

9. A 1250-gram mass has a weight of 23.5 N on an unknown planet. What is the surface gravity of this planet?

a) 9.80 m/s^2 b) 18.8 m/s^2 c) 9.40 m/s^2

d) 4.90 m/s^2 e) 53.2 m/s^2

$w = mg$

$g = \frac{w}{m} = \frac{23.5\,N}{1.25\,kg} = 18.8\,m/s^2$

10. An isothermal process, such as an object changing state, occurs in an isolated system. If this process causes a change of entropy of +988 J/K in the system when 3.45×10^5 Joules of thermal energy is added to the system, what is the temperature of the system?

a) 5880 K   b) 4220 K   c) 1220 K   d) 989 K   e) 349 K

$\Delta S = Q/T, \quad T = \frac{Q}{\Delta S} = \frac{3.45\times10^5\,J}{988\,J/K} = 349\,K$

Part B: Easy Multiple Choice (20 points total, 1 point each). Circle the best answer.

11. P as a function of T and V is known as what in thermodynamics?

a) conservation of momentum   b) conservation of energy   c) Kepler's 3rd Law

d) Kepler's 1st Law   e) equation of state

12. The internal friction of a fluid is called its

a) turbulence b) inertia c) dynamics d) velocity e) viscosity

13. Which of the following processes is the one which no energy is transferred by heat between the system and its surroundings?

a) isothermal b) isobaric c) isochoric

d) isoenthalpic e) none of these

(adiabatic)

14. Which of the following describes an incompressible fluid?

a) The pressure is uniform throughout the fluid.

b) The temperature is uniform throughout the fluid.

c) The heat is uniform throughout the fluid.

d) The density is uniform throughout the fluid.

e) The internal energy is uniform throughout the fluid.

15. Which of the following is a true statement describing the second law of thermodynamics?

a) For every action there is an opposite reaction.

b) Planets move faster when they are closer to the Sun.

c) The entropy of a closed system must remain constant and the Helmholtz free energy describes that entropy.

d) Heat can only be transmitted by the flow of photons.

e) Isolated systems tend towards greater disorder and entropy is a measure of that disorder.

16. When a final state can be returned to its initial state, the process is called

a) irreversible b) reversible c) isothermal d) adiabatic e) isobaric

17. Which of the following state variables describes the 'disorder' of the material that makes up an object?

a) energy b) enthalpy (c) entropy d) sublimation e) pressure

18. Which law shows us the direction in which time progresses?

a) first law of motion b) second law of motion c) third law of motion

d) law of relativity (e) none of the above

(2nd law of thermo)

19. An object moves in uniform motion. Which of the following must be true concerning the object?

a) The object is accelerating.

b) The object is decelerating.

c) The object is obeying Kepler's 3rd law.

(d) There is no external force acting on the object. (since v is constant, a = 0, hence F = 0)

e) The object is isothermal.

20. The measure of matter's resistance to change in motion is better known as

a) conduction b) acceleration (c) inertia

d) voltage e) none of these

21. An ideal absorber is called a(n)

a) Carnot engine (b) blackbody c) whitebody

d) opaque e) transparent

22. Whether a fluid becomes turbulent is dependent on its

(a) Reynold's number b) Boltzmann's number c) Planck's number

d) Avogadro's number e) wrong number

23. The energy associated with the microscopic components of a system — atoms and molecules is called

a) moment of inertia b) heat c) internal energy
d) entropy e) inertia

24. Which of the following does <u>not</u> describe an ideal gas?

a) The gas pressure is independent of the gas temperature.
b) The molecules obey Newton's laws of motion, but as a whole they move randomly.
c) The molecules interact only by short-range forces during elastic collisions.
d) The molecules make elastic collisions with the walls.
e) The gas is homogeneous.

25. The farthest point from the Sun on a planetary orbit is called the

a) semimajor axis b) semiminor axis c) aphelion
d) perihelion e) eccentricity

26. The general form of the first law of thermodynamics is nothing more than the conservation of

a) momentum b) angular momentum c) mass
d) energy e) entropy

27. Ice skaters rotate faster when they bring their arms in towards their bodies due to the conservation of

a) momentum b) moment of inertia c) angular momentum
d) energy e) mass

28. The ratio of the work done by a system to the heat input is called

a) coefficient of performance b) entropy c) enthalpy

d) thermal efficiency e) Homer

29. The time it takes for the Earth to orbit the Sun once is a

a) second b) day c) month d) year e) century

30. The *constant temperature* gas law is referred to as whose law?

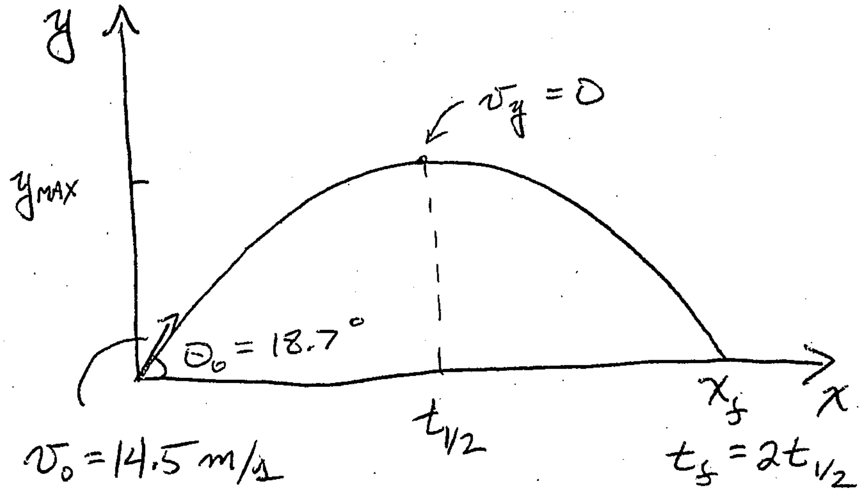
a) Charles' b) Bolye's c) Gay-Lussac's d) Holye's e) Kepler's

Part C: Problems (40 points total, 10 points each).

31. A high hurdle jumper starts a jump leaving the ground at an angle of 18.7° with a velocity of 24.5 m/s. (a) How long does it take this jumper to reach her maximum height? (b) What is this maximum height? (c) How far does this jumper travel horizontally before she lands on the ground? (**Ignore air friction. Make sure you include a diagram. As always, show** <u>**all**</u> **work!**)

$$v_{0x} = v_0 \cos\theta_0 = (24.5\ \tfrac{m}{s}) \cos 18.7^\circ = 23.2\ m/s$$

$$v_{0y} = v_0 \sin\theta_0 = (24.5\ \tfrac{m}{s}) \sin 18.7^\circ = 7.86\ m/s$$



$v_0 = 14.5\ m/s$
$t_0 = 0$
$x_0 = 0,\ y_0 = 0$

a) $t_{1/2} = ?$

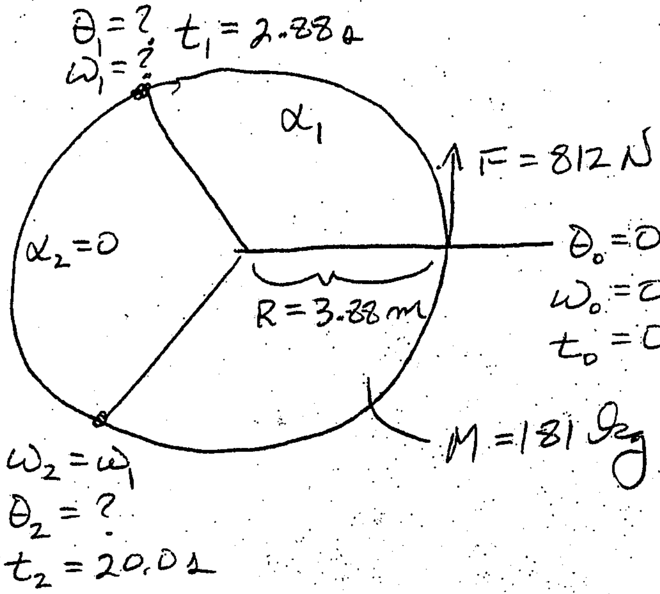
$$v_y = v_{0y} - g(t - t_0)$$
$$0 = v_{0y} - g\,t_{1/2}, \quad t_{1/2} = \frac{v_{0y}}{g} = \frac{7.86\ m/s}{9.80\ m/s^2} = \boxed{0.802\ s}$$

b) $$y = y_0 + v_{0y}(t - t_0) - \tfrac{1}{2}g(t - t_0)^2$$
$$y_{MAX} = 0 + v_{0y}t_{1/2} - \tfrac{1}{2}g t_{1/2}^2$$
$$= (7.86\ m/s)(0.802\ s) - \tfrac{1}{2}(9.80\ \tfrac{m}{s^2})(0.802\ s)^2 = \boxed{3.15\ m}$$

c) $$t_f = 2t_{1/2} = 1.60\ s$$
$$x = x_0 + v_{0x}(t - t_0) = v_{0x}t_f = (23.2\ \tfrac{m}{s})(1.60\ s)$$
$$= \boxed{37.2\ m}$$

This runner must be bionic!

32. A circular disk of radius 3.88 meters and mass 181 kg has a cord attach to its circumference edge. A force of 812 N is applied to this cord in a tangential direction to the disk which causes the disk to start spinning from rest. This force is applied for a total of 2.88 seconds and after this time, the disk continues to rotate at a constant angular speed. (a) What is the moment of inertia of this disk? (b) What is the angular speed of the disk at 2.88 seconds? (c) How many revolutions will the disk make in 20.0 seconds? (d) What is the rotational kinetic energy of this disk at the 20.0 second mark? (Note that $I = (1/2)MR^2$ for a disk spinning about its center. (**Ignore friction in the bearings. Make sure you include a diagram. Show all work!**)



a) $I = \frac{1}{2}MR^2$

$= \frac{1}{2}(181\ \text{kg})(3.88\ \text{m})^2$

$= \boxed{1360\ \text{kg}\,\text{m}^2}$

b) $\tau = Fd = I\alpha,\ d = R$

$\alpha_1 = \frac{FR}{I}$

$= \frac{(812\ \text{N})(3.88\ \text{m})}{1360\ \text{kg}\,\text{m}^2} = 2.31\ \text{rad/s}^2$

$\omega_1 = \omega_0 + \alpha_1(t_1 - t_0) = \alpha_1 t_1 = (2.31\ \frac{\text{rad}}{\text{s}^2})(2.88\ \text{s})$

$= \boxed{6.66\ \text{rad/s}}$

c) $\theta_2 = \theta_1 + \omega_1(t_2 - t_1) + \frac{1}{2}\alpha_2(t_2 - t_1)^2$ (with $\alpha_2 = 0$)

$\theta_1 = \theta_0 + \omega_0(t_1 - t_0) + \frac{1}{2}\alpha_1(t_1 - t_0)^2 = \frac{1}{2}\alpha_1 t_1^2$

$= \frac{1}{2}(2.31\ \text{rad/s}^2)(2.88\ \text{s})^2 = 9.59\ \text{rad}$

$\theta_2 = 9.59\ \text{rad} + (6.66\ \frac{\text{rad}}{\text{s}})(20.0\ \text{s} - 2.88\ \text{s})$

$= 124\ \text{rad} \times \frac{1\ \text{rev}}{2\pi\ \text{rad}} = \boxed{19.7\ \text{rev}}$

d) $KE_r = \frac{1}{2}I\omega_2^2 = \frac{1}{2}(1360\ \text{kg}\,\text{m}^2)(6.66\ \frac{\text{rad}}{\text{s}})^2 = \boxed{3.02\times10^4\ \text{J}}$

33. A piston in a cylinder of radius 13.2 cm moves without friction. The cylinder is filled with CO_2 gas. Initially the volume in the cylinder is 2.44 liters, pressure of 1.22 atm, and temperature 32.3°C. The piston is compressed to a new volume of 0.556 liters. At this new volume, the pressure of the CO_2 in the cylinder has increased by a factor of 2.66 times its initial value. (a) How many moles of CO_2 are in the cylinder? (b) How many CO_2 molecules are in the cylinder? (c) What is the final temperature (in °C) in the cylinder when the volume is at its minimum? (Assume no gas leaks from the cylinder during its motion. **Show all work!**)

$$V_i = 2.44\ \text{li} \times \frac{10^{-3}\ m^3}{1\ \text{li}} = 2.44 \times 10^{-3}\ m^3$$

$$P_i = 1.22\ \text{atm} \times \frac{1.013\times10^5\ \text{Pa}}{1\ \text{atm}} = 1.24\times10^5\ \text{Pa},\quad P_f = 2.66\,P_i$$

$$T_i = 32.3^\circ C + 273.15 = 305.5\ K$$

$$V_f = 0.556\ \text{li} \times \frac{10^{-3}\ m^3}{1\ \text{li}} = 5.56\times10^{-4}\ m^3$$

a) $PV = nRT$, $n = \frac{P_i V_i}{R T_i} = \frac{(1.24\times10^5\ \text{Pa})(2.44\times10^{-3}\ m^3)}{(8.314\ \frac{J}{K\ mol})(305.5\ K)}$

$= \boxed{0.119\ \text{mol}}$

b) $\#\text{ of molecules} = n N_A = (0.119\ \text{mol})(6.023\times10^{23}\ \frac{\text{molecules}}{\text{mol}})$

$= \boxed{7.15\times10^{22}\ \text{molecules}}$

c) $\frac{P_f V_f}{P_i V_i} = \frac{nRT_f}{nRT_i} = \frac{T_f}{T_i}$

$$T_f = T_i\left(\frac{P_f}{P_i}\right)\left(\frac{V_f}{V_i}\right) = (305.5\ K)(2.66)\left(\frac{0.556\ \text{li}}{2.44\ \text{li}}\right)$$

$= 185.17\ K - 273.15$

$= \boxed{-88.0^\circ C}$

34. A total work of 1590 Joules is applied to a movable piston which causes the volume in a cylinder to contract. Assume this cylinder is filled with 84.6 mol of an ideal gas which remains isobaric at a pressure of 8.60 atm as the piston moves. If the initial temperature of the gas is 12.6°C, what is the final temperature of the gas (in °C) after the work is performed? (Assume no gas leaks from the cylinder during its motion. **Show all work!**)

$W = 1590\ \text{J} \qquad n = 84.6\ \text{mol}$

$P = 8.60\ \text{atm} \times 1.013\times 10^{5}\ \frac{\text{Pa}}{\text{atm}} = 8.71\times 10^{5}\ \text{Pa} = \text{const.}$

$T_i = 12.6^\circ\text{C} + 273.15 = 285.8\ \text{K}$

$W = -P\Delta V$

$\Delta V = -\frac{W}{P} = -\frac{1590\ \text{J}}{8.71\times 10^{5}\ \text{Pa}} = -1.83\times 10^{-3}\ \text{m}^3$

$PV_f - PV_i = nRT_f - nRT_i$

$P\Delta V = nR\Delta T = nR(T_f - T_i)$

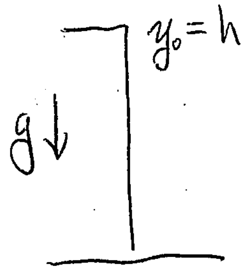
$T_f = T_i + \frac{P\Delta V}{nR} = 285.8\ \text{K} + \frac{(8.71\times 10^{5}\ \text{Pa})(-1.83\times 10^{-3}\ \text{m}^3)}{(84.6\ \text{mol})(8.314\ \frac{\text{J}}{\text{K mol}})}$

$= 285.8\ \text{K} + (-2.26\ \text{K})$

$= 283.5\ \text{K} - 273.15 = \boxed{10.4^\circ\text{C}}$

Extra Credit Problem (10 points, 5 points each — do this only if you have time).

35. You are on the home planet of the Klingon Empire. You drop a ball of mass 1.24 kg from a 334 m tower and it takes 6.54 s to reach the ground. The diameter of the Klingon home world is 1.55 times the diameter of the Earth. What is the mass of the Klingon home world? **(Show all work!)**



$y_0 = h = 334\,m,\ t_0 = 0,\ v_{0y} = 0$

$t = 6.54\,s,\ y = 0$

$y = y_0 + v_{0y}(t - t_0) - \frac{1}{2} g (t - t_0)^2$

$0 = h - \frac{1}{2} g t^2$

$g = \frac{2h}{t^2} = \frac{2(334\,m)}{(6.54\,s)^2} = 15.6\,\frac{m}{s^2}$

$g = GM/r^2$

$M = \frac{g r^2}{G} = \frac{g(1.55 R_\oplus)^2}{G}$

$= \frac{(15.6\,\frac{m}{s^2})(1.55 \times 6.37 \times 10^6\,m)^2}{6.673 \times 10^{-11}\,Nm^2/kg^2}$

$= \boxed{2.28 \times 10^{25}\,kg}$

$\times \frac{1\,M_\oplus}{5.98 \times 10^{24}\,kg}$

$= \boxed{3.81\,M_\oplus}$

36. A metal rod that is 92.2 cm long at 22.2°C is observed to be 94.6 cm long at 96.6°C. What is the coefficient of linear expansion of this metal? **(Show all work!)**

$\Delta L = \alpha L_0 \Delta T$

$\alpha = \frac{\Delta L}{L_0} \Delta T^{-1} = \frac{(94.6\,cm - 92.2\,cm)}{92.2\,cm} (96.6°C - 22.2°C)^{-1}$

$= \frac{0.0260}{74.4°C} = \boxed{3.50 \times 10^{-4}\,°C^{-1}}$