**Physics 201, Final Exam** **Name (printed)** Solution

**On my honor as a Texas A&M University student, I will neither give nor receive unauthorized help on this exam.**

**Name (signed)** ______________________

The fill-in-the-blank and multiple-choice problems carry no partial credit.
Put your answer in the **underlined space** below a **fill-in-the-blank problem**.

**Circle** the correct answer or answers for each **multiple-choice problem**.
(An answer is approximately correct if it is correct to 2 significant figures.)

**In the work-out problems, you are graded on your work, with partial credit.**
(The answer by itself is not enough, and you receive credit only for your work.)
Be sure to include the correct units in the answers, and give your work in the space provided.

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heat of fusion for water $= 334 \times 10^3$ J/kg)
heat capacity of water $= 4.19 \times 10^3$ J/(kg K)
heat capacity of ice $= 2.01 \times 10^3$ J/(kg K)

1 atm $= 1.013 \times 10^5$ Pa
1 L $= 10^{-3}$ m$^3$ ,
1 kg $= 10^3$ g [here g means gram of course]

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1. (4) If a 5 lb force is required to keep a block of wood 1 ft beneath the surface of water, the force required to keep it 2 ft below the surface is

(a) 2.5 lb
(b) 5 lb
(c) 10 lb

same buoyant force

representation of Archimedes on Mathematics Fields Medal

https://en.wikipedia.org/wiki/File:FieldsMedalFront.jpg

2. (4) A cylindrical metal bar conducts heat at a rate $R$ from a hot reservoir to a cold reservoir. If both its *length* and its *diameter* are doubled, it will conduct heat at a rate

(a) $R$
(b) $2R$
(c) $4R$
(d) $8R$

$$H = kA\frac{T_H - T_C}{L} \propto \frac{d^2}{L} \quad \text{and} \quad \frac{(2d)^2}{2L} = 2$$

$$\text{i.e.,} \quad \frac{H'}{H} = \frac{(d')^2/L'}{d^2/L} = \frac{(2d)^2/2L}{d^2/L} = 2$$

$$\text{or } \boxed{H' =} 2H = \boxed{2R}$$


http://webs.morningside.edu/slaven/Physics/entropy/entropy5.html

3. (4) Which of the following processes would be a violation of the second law of thermodynamics? (There may be more than one correct choice.)

(a) All of the kinetic energy of an object is transformed into heat.

(b) All the heat put into the operating gas of a heat engine during one cycle is transformed into work.

(c) A refrigerator removes 100 cal of heat from milk while using only 75 cal of electrical energy to operate.

(d) A heat engine does 25 J of work while expelling only 10 J of heat to the cold reservoir.

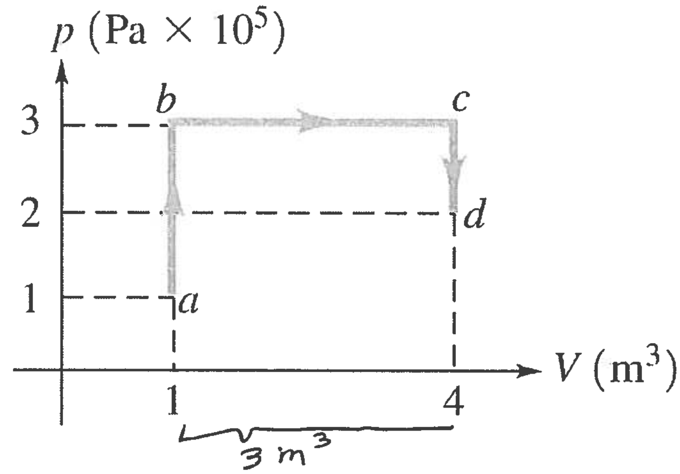
4. (4) Consider an ideal gas, and let $U$ be the internal energy, $n$ the number of moles, $C_V$ the molar heat capacity at constant volume, and $T$ the temperature.

The formula $\Delta U = nC_V \Delta T$ is true for (circle all correct answers)

(a) an isothermal process
(b) an adiabatic process
(c) a process at constant volume
(d) a process at constant pressure

any process

5. (4) For the process shown in the $pV$ diagram, the total work in going from $a$ to $d$ along the path shown is




(a) $1.5\times10^5$ J
(b) $9\times10^5$ J
(c) $6\times10^5$ J
(d) $1\times10^5$ J
(e) $12\times10^5$ J

$p\Delta V$
$= (3\times10^5 \frac{N}{m^2})(3\ m^3)$
$= 9\times10^5 J$

6. (4) A chunk of ice with a mass of 20 kg falls into the ocean and melts. Initially, and throughout the melting process, it is at a temperature of $0^\circ$ C. Calculate the change in the entropy of the ice, as it is converted to liquid water, still at $0^\circ$ C.

change in entropy of ice = $2.45\times10^4 \frac{J}{kg}$
[or 24,500 J/kg]

$0^\circ C = 273 K$

$\boxed{\Delta S =} \frac{Q}{T} = \frac{(20\ kg)(334\times10^3 \frac{J}{kg})}{273\ K}$

$= \boxed{2.45\times10^4 \frac{J}{K}}$

7. (4) In an inelastic collision, which of the following are conserved?

(a) kinetic energy
(b) momentum
(c) entropy
(d) none of the above

8. (4) An organ pipe open at one end, but closed at the other, is vibrating in its fundamental mode, producing sound of frequency 1000 Hz. If you now open the closed end, the new fundamental frequency will be

(a) 4000 Hz
(b) 2000 Hz
(c) 1000 Hz
(d) 500 Hz
(e) 250 Hz

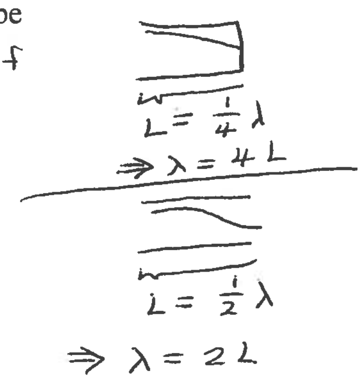
closed: $f_1 = \frac{v}{4L}$

open: $\boxed{f_1' =} \frac{v}{2L}$

$= 2 \frac{v}{4L} = \boxed{2f_1}$

$v = \frac{\lambda}{T} = \lambda f$

$\Rightarrow f = \frac{v}{\lambda}$



9. (4) A steel ball is dropped from the top of the Leaning Tower of Pisa, which is 56 m high. With air resistance neglected, approximately how long does it take the ball to hit the ground?

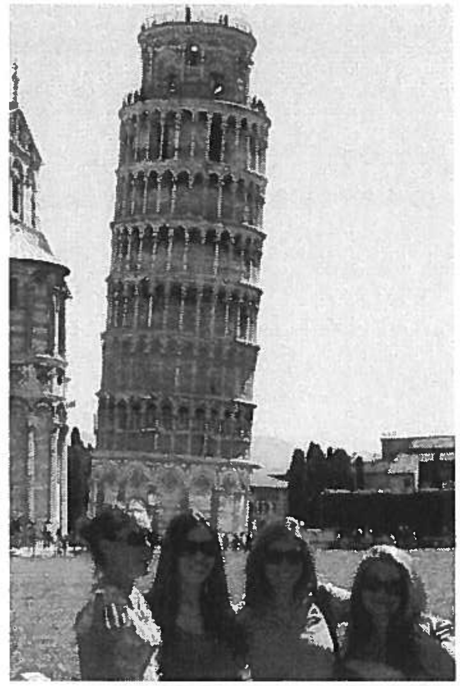
$$y - y_i = v_{oy} t + \frac{1}{2} a_y t^2$$

(a) 2.4 s
(b) 3.4 s
(c) 5.7 s
(d) 11.4 s
(e) none of the above

$$\Rightarrow -56\ m = 0 - \frac{1}{2} g t^2$$

$$\Rightarrow \boxed{t =} \sqrt{\frac{(2)(56\ m)}{9.8\ m/s^2}}$$

$$= \boxed{3.4\ s}$$



Texas A&M students in Pisa, Italy, as part of Study Abroad program (history, culture, astronomy)

10. (4) Now suppose that you are climbing the Leaning Tower, and you throw your cellphone to a friend on the ground, who catches it at a point 30 m below the point where you released it.

You threw it straight out, with an initial horizontal velocity of 10 m/s (and zero initial vertical velocity).

Again neglecting air resistance, what is the speed of the cellphone when your friend catches it?

(a) 24 m/s
(b) 26 m/s
(c) 588 m/s
(d) 688 m/s
(e) none of the above

$$v_y^2 = v_{oy}^2 + 2 a_y (y - y_o)$$

$$= 0 + 2 (-9.8 \tfrac{m}{s^2})(-30 m)$$

$v_y = \pm 24.2$ m/s with $-$ being physical

$$v_x^2 = v_{ox}^2 + 2 a_x (x - x_o) = v_{ox}^2 + 0$$

$\Rightarrow v_x = v_o = 10$ m/s (of course)

so $v^2 = \sqrt{v_x^2 + v_y^2} = \sqrt{100 + 586}$ m/s

$$\Rightarrow \boxed{v = 26.2\ m/s}$$

11. Oxygen ($O_2$) has a molar mass of 32.0 g/mol.

(a) (5) Calculate the root-mean-square speed of an oxygen molecule at 27 °C.

$$27^\circ C = (27 + 273)\ K = 300\ K$$

$$\boxed{v_{rms} =} \sqrt{\frac{3RT}{M}}$$

$$= \sqrt{\frac{(3)(8.314\ \frac{J}{mol\cdot K})(300\ K)}{32.0\times 10^{-3}\ kg/mol}}$$

$$= \boxed{483\ m/s}$$

(b) (5) Calculate its average translational kinetic energy.

$$\boxed{K_{av} =} \frac{3}{2}kT = \frac{3}{2}(1.381\times 10^{-23}\ \frac{J}{molecule\cdot K})(300\ K)$$

$$= \boxed{6.21\times 10^{-21}\ J}$$

or else $1\ u = 1.661\times 10^{-27}\ kg$

$$\Rightarrow m = (32.0\ u)\frac{1.661\times 10^{-27}\ kg}{1\ u} = 5.32\times 10^{-26}\ kg$$

$$\Rightarrow \boxed{K_{av} =} \frac{1}{2}m v_{rms}^2$$

$$= \frac{1}{2}(5.32\times 10^{-26}\ kg)(483\ \frac{m}{s})^2$$

$$= \boxed{6.21\times 10^{-21}\ J}$$

12. (13) A spherical metal container holds 1.00 L of hot water at a temperature of 90 °C. The emissivity of the metal surface is 0.50 (and the metal is a very good conductor of heat). The surroundings are at a temperature of 20 °C. Calculate the net rate of heat loss from the container by radiation.

$$H = A e \sigma (\underset{\text{emission}}{T^4} - \underset{\text{absorption}}{T_s^4})$$

$T = (273 + 90)\,K = 363\,K$

$T_s = 293\,K$


get $A$ from $V$ via $r$: $A = 4\pi r^2$ & $V = \frac{4}{3}\pi r^3$

first $r = \left(\frac{3V}{4\pi}\right)^{1/3} = \left(\frac{3}{4\pi} \cdot 1\,L \cdot \frac{10^{-3}\,m^3}{1\,L}\right)^{1/3}$

$= (2.387 \times 10^{-4})^{1/3}\ m$

$= 0.0621\ m$

then $A = 4\pi\,(0.0621\ m)^2 = 0.0485\ m^2$

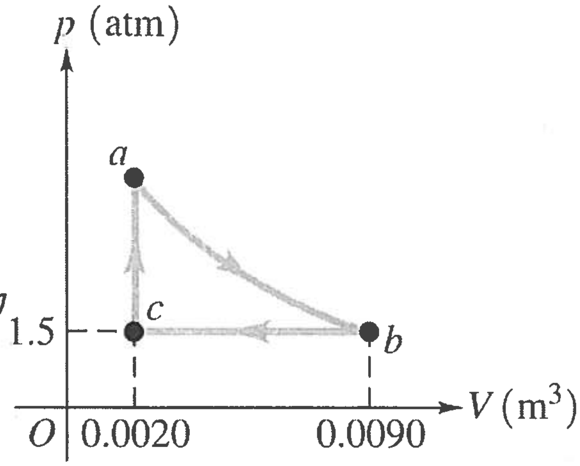
so $\boxed{H =}\ (0.0485\ m^2)(0.50)\left(5.67 \times 10^{-8}\ \frac{W}{m^2 K^4}\right)$

$\times \left[(363\ K)^4 - (293\ K)^4\right]$

$= \left(0.1375 \times 10^{-8}\ \frac{W}{K^4}\right)\left(1.736 \times 10^{10} - 0.737 \times 10^{10}\right)$

$\boxed{\approx 14\ W}$

13. The $pV$ diagram shows a cycle of a heat engine that uses 0.500 mole of a diatomic ideal gas having $\gamma = 1.40$. The curved part $ab$ of the cycle is adiabatic. The internal energy changes by the following amounts: $\Delta U_{a \to b} = -3000$ J, $\Delta U_{b \to c} = -2500$ J.




(a) (1) Calculate the final internal energy change, $\Delta U_{c \to a}$.

$\Delta U_{c \to a} =$ 5500 J

$\Delta U_{total} = 0$

$\boxed{\Delta U_{c \to a}} = 3000\ \text{J} + 2500\ \text{J} = \boxed{5500\ \text{J}}$

(c) (4) Calculate the pressure of the gas at point $a$.

$p_a =$ $1.25 \times 10^6$ Pa

$$p_a V_a^{\gamma} = p_b V_b^{\gamma} \Rightarrow \boxed{p_a} = p_b \left(\frac{V_b}{V_a}\right)^{\gamma}$$

$$= (1.5\ \text{atm})\left(\frac{1.013 \times 10^5\ \text{Pa}}{1\ \text{atm}}\right)\left(\frac{0.0090}{0.0020}\right)^{1.4}$$

$$= \boxed{1.25 \times 10^6\ \text{Pa}}$$

(c) (3) Calculate the heat added during $c \to a$.

heat added during $c \to a =$ 5500 J

$$\Delta U_{c \to a} = Q_{c \to a} - \underbrace{W_{c \to a}}_{=0}$$

$$\boxed{Q_{c \to a}} = \Delta U_{c \to a} = \boxed{5500\ \text{J}}$$

(d) (3) Calculate the heat added during $b \to c$.

heat added during $b \to c =$ $-3564$ J

$$W_{b \to c} = p_b \Delta V_{b \to c}, \quad Q = \Delta U + W$$

$$\boxed{Q_{b \to c}} = -2500\ \text{J} + (1.5\ \text{atm})\left(1.013 \times 10^5\ \frac{\text{Pa}}{\text{atm}}\right) \times (0.0020 - 0.0090)\ \text{m}^3$$

$$= -2500\ \text{J} - 1064\ \text{J}$$

$W_{b \to c}$

$$= \boxed{-3564\ \text{J}}$$

(e) (3) Calculate the total heat added during the entire cycle.

total heat added = 1936 J

$$\boxed{Q} = (5500 - 3564)\ \text{J} = \boxed{1936\ \text{J}}$$

(f) (3) Calculate the total work done during the entire cycle.

total work done = 1936 J

$\boxed{W} = Q = \boxed{1936\ \text{J}}$ since $\Delta U = Q - W$ & $\Delta U = 0$ for full cycle

(g) (3) Calculate the efficiency of this model engine.

efficiency = 35 %

$$\boxed{e} = \frac{W}{Q_H} = \frac{W}{Q_{c \to a}} = \frac{1936\ \text{J}}{5500\ \text{J}} = 0.352$$

$\boxed{\approx 35\%}$

14. (12) A steel wire 2.00 m long with a circular cross section must stretch no more than 0.20 cm when a 400 N weight is hung from one of its ends. Calculate the minimum diameter that this wire must have.

Young's modulus of steel $= 2.0\times10^{11}$ Pa

minimum diameter = $1.6\times10^{-3}$ m

$$\frac{F_\perp}{A} = Y\frac{\Delta l}{l_0} = (2.0\times10^{11}\ \text{Pa})\frac{0.20\times10^{-2}\ \text{m}}{2.00\ \text{m}}$$

$$= 2.0\times10^{8}\ \text{Pa} \qquad \text{with } F_\perp = 400\ \text{N}$$

$$\Rightarrow A = \frac{400\ \text{N}}{2.0\times10^{8}\ \text{Pa}} \qquad \left[1\ \text{Pa} = 1\ \frac{\text{N}}{\text{m}^2}\right]$$

$$= 2.00\times10^{-6}\ \text{m}^2$$

$$A = \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = \frac{1}{4}\pi d^2$$

$$\Rightarrow \boxed{d =}\sqrt{\frac{4A}{\pi}} = \sqrt{\frac{(4)(2.00\times10^{-6}\ \text{m}^2)}{\pi}}$$

$$= \boxed{1.6\times10^{-3}\ \text{m} = 1.6\ \text{mm}}$$

15. A 2.0 kg wooden ball is suspended from a vertical wire 10 m long. Clint Eastwood fires a .44 Magnum bullet, with a mass of 0.02 kg, into the ball. The ball (with bullet embedded) swings out and upward until it has reached a height of 0.70 meter (relative to its starting point), when it stops and begins to swing back.

(a) (5) Calculate the potential energy of the system (ball plus bullet) at the highest point.

potential energy at highest point = 13.8 J

$$Mgy = (2.02\ kg)(9.8\ m/s^2)(0.70\ m)$$
$$= \boxed{13.8\ J} \qquad [1\ J = 1\ kg\ m/s^2]$$

(b) (5) Calculate the velocity of the system (ball plus bullet) at the lowest point.

velocity at lowest point = 3.7 m/s

$$\frac{1}{2}Mv^2 = K$$
$$\Rightarrow \boxed{v =} \sqrt{\frac{2K}{M}} = \sqrt{\frac{(2)(13.8\ J)}{2.02\ kg}} = \boxed{3.7\ m/s}$$
$$\left[\text{or } \frac{1}{2}\cancel{M}v^2 = \cancel{M}gh \Rightarrow v = \sqrt{2gh} = \sqrt{2(9.8\ m/s^2)(0.70\ m)} = 3.7\ m/s\right]$$

(c) (5) Calculate the speed of the bullet before it hit the ball. (So we have determined the gun's muzzle velocity.)

speed of bullet before it hit ball = 374 m/s

$$mV = Mv$$
$$\Rightarrow \boxed{V} = \frac{Mv}{m} = \frac{(2.02\ kg)(3.7\ m/s)}{0.02\ kg} \boxed{\approx 374\ m/s}$$

16. A solid disk has a radius of $R = 0.10$ m and a mass of $M = 2.0$ kg. It begins rolling up a slope without slipping. The slope is $\theta = 20^\circ$ above the horizontal, and the disk has an initial speed of $v_0 = 3.0$ m/s. We wish to calculate how long it will take for the disk to come to a stop.

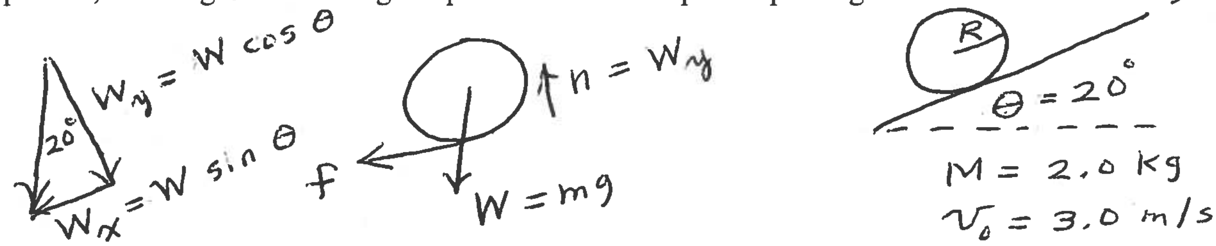
There are 2 unknowns:
(i) the frictional force $f$ acting at the circumference of the disk, a distance $R$ from the center
(ii) the center of mass acceleration $a_{cm}$.

We will have 2 equations.

Eq. (1): the translational equation net force $= M\,a_{cm}$

Eq. (2): the rotational equation torque $= I_{cm}\,\alpha$

(a) (2) Draw a picture, showing $\theta$ and taking the positive $x$ axis to point up along the inclined surface. $\nearrow x$




(b) (2) Write down Eq. (1) (involving force) in terms of $f$, $M$, the acceleration of gravity $g$, $\theta$, and $a_{cm}$.

$$-Mg\sin\theta - f = M a_{cm} \quad (1)$$

(c) (2) Write down Eq. (2) (involving torque) in terms of $R$, $f$, $I_{cm}$, and $\alpha$.

$$-Rf = I_{cm}\,\alpha \quad (2)$$

clockwise torque is negative

(d) (2) Write $\alpha$ in term of $a_{cm}$ and $R$.

$$a_{cm} = -R\alpha \Rightarrow \boxed{\alpha = -\frac{a_{cm}}{R}}$$

since positive (counterclockwise) rotation gives negative motion in $x$ direction

(e) (2) Using the fact that $I_{cm} = \frac{1}{2}MR^2$, and your answers in Parts (c) and (d), write $f$ in terms of $M$ and $a_{cm}$.

$$-Rf = \left(\tfrac{1}{2}MR^2\right)\left(-\frac{a_{cm}}{R}\right) \Rightarrow \boxed{f = \tfrac{1}{2}M a_{cm}}$$

(f) (2) Substitute your result for $f$ in Part (e) into Eq. (1), so that you have an equation with only the single unknown $a_{cm}$.

$$-Mg\sin\theta - \frac{1}{2}\cancel{M}a_{cm} = Ma_{cm}$$

$$\Rightarrow \quad -g\sin\theta = \frac{3}{2}a_{cm}$$

(g) (2) Show that $a_{cm} = -\frac{2}{3}g\sin\theta$.

above equation in (f) $\Rightarrow \boxed{a_{cm} = -\frac{2}{3}g\sin\theta}$

**You may use the result of Part (g) for full credit in the parts below even if you did not derive it.**

(h) (2) Write down the equation that relates the velocity $v$ at the highest point that the disk reaches (before starting to roll back down) to the initial velocity $v_0$, the acceleration $a_{cm}$, and the time $t$ that elapses until it reaches this point.

$$v = v_0 + a_{cm}t$$

$$\Rightarrow 0 = v_0 - \left(\frac{3}{2}g\sin\theta\right)t$$

(i) (2) Substitute the result of Part (g) into the equation of Part (h), and then find $t$ in terms of $v_0$, $g$, and $\sin\theta$.

above equation in (h) $\Rightarrow \boxed{t = \frac{3v_0}{2g\sin\theta}}$

(j) (2) Calculate the time $t$ required for the disk to come to a stop.

$$\boxed{t =} \frac{(3)(3.0\ m/s)}{2(9.8\ m/s^2)\sin 20^\circ} = \boxed{1.34\ s}$$

17. A mass $m_{A\ell}$ of aluminum is completely encased within a mass $m_{Au}$ of gold (chemical symbol Au for the Latin word aurum), with total mass $m = m_{A\ell} + m_{Au}$. The total volume is $V = V_{A\ell} + V_{Au}$. The mass densities are $\rho_{A\ell} = 2.70\times10^3$ kg/m$^3$ and $\rho_{Au} = 19.32\times10^3$ kg/m$^3$, with $\rho_{\text{water}} = 1.000\times10^3$ kg/m$^3$.

The total weight of this hunk of metal is 50.0 N. When it is immersed in water, its apparent weight (measured with a spring balance) is 43.0 N.

$$\boxed{m =} \frac{W}{g} = \frac{50.0\ N}{9.8\ m/s^2} = \boxed{5.102\ kg}$$

(a) (4) Calculate the total mass $m$.

total mass = 5.10 kg

(b) (4) Using the buoyant force, calculate the total volume $V$.

total volume = $7.14\times10^{-4}\ m^3$

$$\underset{\underset{\underset{7.0\ N}{\shortparallel}}{50.0\ N - 43.0\ N}}{\overset{}{F_B}} = (\rho_{water} V) g = \left(10^3 \frac{kg}{m^3}\right) V \left(9.8 \frac{m}{s^2}\right) \Rightarrow \boxed{V = 7.14\times10^{-4}\ m^3}$$

(c) (4) Obtain an expression for the total mass $m$ in terms of $\rho_{A\ell}$, $V_{A\ell}$, $\rho_{Au}$, and $V_{Au}$.

$$\boxed{m =} m_{A\ell} + m_{Au} = \boxed{\rho_{A\ell} V_{A\ell} + \rho_{Au} V_{Au}}$$

(d) (4) You now have two equations in the two unknowns $V_{A\ell}$ and $V_{Au}$. Use them to obtain $V_{Au}$ in terms of $\rho_{Au}$, $V$, $m$, and $\rho_{A\ell}$. (You might write one equation as $V_{A\ell} = V - V_{Au}$, and then substitute into the other equation to find $V_{Au}$.)

$$V_{A\ell} = V - V_{Au}$$

$$\Rightarrow m = \rho_{A\ell}(V - V_{Au}) + \rho_{Au} V_{Au}$$

$$\Rightarrow m - \rho_{A\ell} V = (\rho_{Au} - \rho_{A\ell}) V_{Au}$$

$$\Rightarrow \boxed{V_{Au} =} \frac{m - \rho_{A\ell} V}{\rho_{Au} - \rho_{A\ell}} = \frac{5.10\ kg - \left(2.70\times10^3 \frac{kg}{m^3}\right)\left(7.14\times10^{-4}\ m^3\right)}{(19.32 - 2.70)\times10^3\ kg/m^3}$$

$$= \frac{3.17\ kg}{16.62\times10^3\ kg/m^3} = 0.19\times10^{-3}\ m^3 = \boxed{1.9\times10^{-4}\ m^3}$$

(e) (4) Calculate the weight $w_{Au}$ of the gold.

Weight of gold = 36 N

$$\boxed{W_{Au} =} (\rho_{Au} V_{Au}) g = \left(19.32\times10^3 \frac{kg}{m^3}\right)\left(1.9\times10^{-4} m^3\right)\left(9.8 \frac{m}{s^2}\right)$$

$$= \boxed{36\ N}$$

(If you were Archimedes, you would report back to the king that this crown is not pure gold, and the maker of the crown would suffer the consequences.)

18. (5 extra credit for **clear answers**) Give 5 independent examples of phenomena involving Bernoulli's principle.

(i) can blow roof off a building

(ii) lift on airplane wing

(iii) can cause constricted blood vessel to collapse

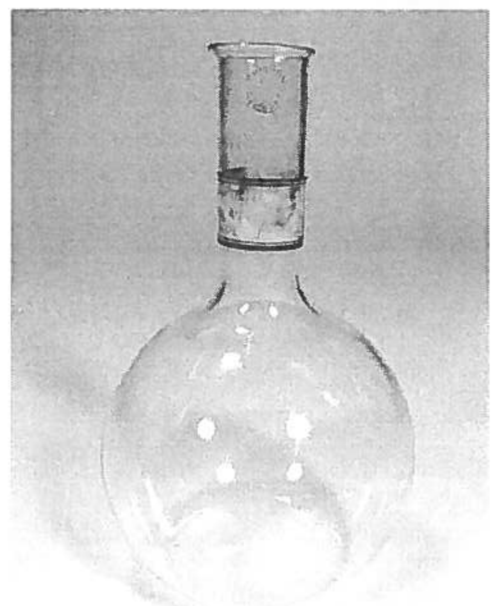
(iv) part of the reason a spinning ball curves

(v) part of the a shower curtain is pulled in

19. (5 extra credit for a **clear answer**). In class we did the **geyser demonstration**: A flask contains a small amount of water which is heated until it boils away. The flask is then immediately turned upside and its open end is placed in a beaker containing blue liquid. After a moment, the blue liquid shoots up into the flask, like a geyser.

Give a **clear explanation** of why this happens for extra credit.

water vapor displaces air in flask, then condenses, creating a partial vacuum, into which "geyser" water is pushed by atmospheric pressure.



**Please have a good break!**