Some things to remember before you begin homework #1 . . .

- Be sure to put your HW in the right box! You won’t get credit for HW handed in late or placed in the wrong box.
- Be sure to staple your assignments (with a REAL staple) or you will not get credit.
- Work all numerical answers to 3 significant figures (i.e. 0.00314 NOT 0.003 or 0.003145632). For intermediate results, keep more than 3 sig figs or you will accumulate rounding errors.
- Work everything algebraically first, then plug numbers in at the very end.
- Before you compare your answers with others, practice using your own abilities to search for errors - check units, take limits, see if it makes sense!
- Don’t be shy about asking for help from fellow classmates, the TA, or Dr. Durfee.
- DO ALL YOUR HOMEWORK - this is how you will learn the material, and this is the BEST way to prepare for exams.

Ok, now you can go to the next page and start your homework.
1. (3 pts) When a particular man is riding on his bike, each of the two tires makes contact with the ground over an area of $9.31 \times 10^{-4} \text{ m}^2$. A gauge on each of the bicycle’s tires reads a gauge pressure of 55 psi (3.792x10^5 Pa). What is the combined mass of the bicycle and the rider? Assume that atmospheric pressure is 1.013 x 10^5 Pa and that the acceleration due to gravity is 9.8 m/s^2.

2. (3 pts) Knowing that the radius of the Earth is $6.37 \times 10^6 \text{ m}$ and that atmospheric pressure at the surface of the Earth is 1.013 x 10^5 Pa, what is the total mass of all of the gas in the Earth’s atmosphere? Assume that the acceleration due to gravity is 9.8 m/s^2 throughout the entire atmosphere.

3. (5 pts) A particular vacuum cleaner can generate pressures as low as 100 Pa at the end of its hose. We place the end of the hose on a big slab of rubber, making a seal with the rubber. We then pull on the hose and pick up the rubber using the suction of the vacuum. (a) If the end of the hose is 2 cm in diameter, what is the mass of the heaviest slab of rubber that it can pick up? (b) Now imagine that your cousin, the door to door salesman, tries to convince you to purchase an expensive “ideal” vacuum cleaner that could produce a pressure of 0 Pa at the end of the hose. What is the mass of the heaviest slab of rubber that it could pick up? (After working this you might want to ask your self how much more effective this vacuum cleaner will be and whether it is worth the extra money?) (c) If we put an adapter on the ideal vacuum cleaner that increased the diameter of the end of the hose to 4 cm, what would the mass of the heaviest piece of rubber that it could pick up be? (d) Now imagine that our ideal vacuum cleaner can run underwater. If we take it 20 meters underwater by what factor will the “suction” force increase compared to the force it generates in air?

Note that the book has an example similar to the following problems, but the wording that they use is a bit confusing — it sounds like they are asking for just the force due to the water, but end up solving for the total force. We’ll solve things piece by piece to make sure things are clear.

4. (6 pts) A dam is made of a thin rectangular slab of concrete which is a distance L wide and a height h tall. The reservoir on the left side of the slab is filled with water with a density $\rho$ to a depth h (of course $h < L$). The pressure of the surrounding atmosphere is $P_0$.

   (a) If the local acceleration due to gravity is $g$, what is the pressure at the top and the bottom of the water in the reservoir?

   (b) What is the force exerted on the dam by the air on the right side of the dam?

   (c) What is the force exerted by the air above the water on the left side of the dam? (Here I want just the force exerted directly by the air, not including the effect that the air has on the pressure of the water, which “indirectly” exerts a force on the dam).

   (d) What is the force exerted on the dam by the water? (Note that this force depends on the water pressure which is influenced by the air pressure above the water — so the answer to this part should depend on $P_0$.

   (e) What is the total force exerted on the dam by the air and the water?

   (f) How much does this total force increase if the pressure of the surrounding atmosphere increases by a factor of 2?

5. (6 pts) Now let’s think about the tendency for the dam to topple over — let’s consider the torque about the bottom of the concrete slab. And to make things simple, let’s assume that the dam is on a planet with no atmosphere, such that $P_0 = 0$ (it’s going to cancel in the end anyway). What is the torque exerted by the water on the dam about a pivot point at the bottom of the concrete slab?

6. (3 pts) Two cylindrical pistons are connected together with a hose and filled with water. The first piston has a diameter of 20 cm. The second piston has a diameter of 35 cm. An 82.2 kg man is standing on the first piston. If the top of the two pistons are initially at the same height, how much mass must be placed on the second piston to keep the man from rising or falling?
7. (4 pts) The Cartesian Diver: Visit the Cartesian diver exhibit on the north-west side of the lobby of the Eyring Science Center. (a) Play with the diver, and read the explanation on the wall. Once you have done this, respond "Yes" to part (a). (b) Why is the diver inside the bottle affected when you squeeze the outside of the bottle?

Extra problems I recommend you work (not to be turned in)

- Show that you get the same answer for problem 5 even if $P_0 \neq 0$.

- Work problems 4 and 5 for a dam which is triangular such that the top of the dam is $L$ wide, and the bottom comes to a point.

- A fishbowl is made from a glass sphere of radius $r$ with a tiny opening at the top. The fishbowl is filled to the top, and a fish is swimming at the very center of the fishbowl. The cat, trying to get to the fish, leans on the table that the fishbowl is on, causing it to accelerate horizontally at a rate $a$. This causes the surface of the water to tilt a tiny amount, but does not cause the water to spill. (a) Which direction will the water tilt — in the direction of the acceleration or away from the acceleration? (b) If the acceleration due to gravity is $g$, what is the pressure at the location of the fish while the bowl is being accelerated?
1. (4 pts) Consider the U-shaped glass vessel shown below. The tube rising up on the left has a cross-sectional area \( A_1 = 4 \text{ cm}^2 \). The tube on the right has a cross-section of \( A_2 = 6 \text{ cm}^2 \). Mercury is poured into the vessel, and then a small amount of water is poured into the left side of the vessel. The column of water is \( H_w = 3.25 \text{ cm} \) tall. The top of the mercury on the left side is \( H_{m1} = 3.01 \text{cm} \) above the bottom of the vessel. What will the height \( H_{m2} \) of the top of the mercury column on the right side be?

2. (4 pts) (a) A thin spherical shell of Aluminum which is 2 meters in diameter contains helium gas at atmospheric pressure. How thick can the aluminum shell be if we want the sphere to float in air? (b) How thick can the aluminum be if the shell is filled with hydrogen rather than helium?

3. (3 pts) A pine board which is 2 meters long, 10 cm wide, and 2 cm thick is floating in a lake. How much of the 2 cm thickness will be above water?

4. (4 pts) Before applying the continuity equation and Bernoulli’s equation to specific problems, let’s examine where the equations come from. This will help you better understand how to use them, what approximations they assume, and how to come up with alternative equations when these approximations are not valid. Imagine that a tube has fluid flowing through it. The tube is bent such that one piece of the tube is at a height \( y_1 \), and a second part of the tube is at a height \( y_2 \). The fluid is flowing in the direction from point 1 to point 2. The cross-sectional area of the tube at the two points is \( A_1 \) and \( A_2 \). Now imagine that at time \( t = 0 \), all of the fluid between point 1 and point 2 has red dye in it, to distinguish it from the rest of the fluid.

   (a) Imagine that during some short interval \( dt \), one edge of the red fluid flows a distance \( dx_1 \) beyond point 1, and the other edge flows a distance \( dx_2 \) beyond point 2. Now imagine that the fluid is incompressible. If the fluid is incompressible, then the rate at which fluid flows past point 1 \( (\text{in m}^3/\text{s}) \) will be exactly the same as the rate it flows past point 2. Use this fact to find a relationship between \( dx_1 \) and \( dx_2 \). Then divide both sides of the equation by \( dt \) to convert it into a relationship between \( v_1 \) and \( v_2 \), the velocity of the fluid at points 1 and 2. This is the continuity equation.

   (b) Now let’s get Bernoulli’s equation by applying conservation of energy to the red fluid. After the edge red fluid has moved a distance \( dx_1 \) past point 1, its kinetic and potential energy will have changed. The net change in its energy must equal the work done on it. So the first step is to find the work done on it as it moves this distance. Let’s assume that the fluid has no viscosity, so that the tube walls do not exert a component of force in the direction of the flow. This means that the only work done on the red fluid is the work done by the pressure of the un-dyed fluid on either side of the red fluid. Find the total work done by the surrounding fluid on the red fluid in terms of \( dx_1 \), \( dx_2 \), the pressure at point one \( P_1 \), and the pressure at point two \( P_2 \).

   (c) How much does the potential energy of the red fluid change as it moves this distance? (Hint, the motion of the fluid is equivalent to taking a tiny piece of the fluid near point 1, accelerating it to velocity \( v_2 \), and putting it up near point 2).
(d) Now let’s assume \textit{laminar flow with no turbulence}. This means that the only kinetic energy that the fluid has is its ordinary translational kinetic energy — there is no energy stored in swirling motion, etc., anywhere in the fluid. How much does the kinetic energy of the red fluid change as it moves this distance?

(e) Add the change in kinetic to the change in potential energy and set it equal to the work done on the fluid. Now take all of the stuff related to point 1 to the left side of the equation, and all of the stuff related to point 2 to the right side of the equation and use the same ideas you used to derive the continuity equation to make this into Bernoulli’s equation:

$$P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2.$$ 

5. (3 pts) You place a nozzle on your garden hose to increase the speed of the water exiting the hose. The output end of the nozzle has an inner diameter of 0.241 cm. The garden hose has an inner diameter of 1.83 cm. (a) If the water comes out of the nozzle at a speed of 1.13 m/s, what is the velocity of the water in the hose? (b) The water coming out of the nozzle is at atmospheric pressure. If the Nozzle is 1.67 meters above the ground, what is the pressure of the water in a piece of the hose which is lying directly on the ground? Assume that the water behaves like an ideal fluid.

6. (4 pts) Water is pumped from a lake up to a village on top of a hill 325 meters above the lake. It is pumped through a pipe with a uniform cross section. The top of the lake and the air in the village are both at atmospheric pressure, so to get the water up to the village a pump is placed near the lake to increase the pressure in the pipe. (a) Assuming that the water behaves like an ideal fluid, what minimum gauge pressure must the pump produce at the bottom of the pipe in order to deliver an infinitesimally small trickle of water to the village? (b) How much must the pressure at the bottom of the pipe increase in order to deliver a flow rate of 0.1 m$^3$/s? (c) How would your answers to (a) and (b) change if we included the effects of viscosity?

7. (4 pts) Imagine that you had a cylindrically shaped cup filled to a height $h$ with water sitting on a level table top. If you poked a small hole in the side of the cup, water would shoot out in an arc and hit the table. (a) If you want to maximize the distance that the water goes before hitting the table, how far from the bottom of the cup should you poke the hole? (b) If I place my hole at this location, how far will the water travel before hitting the table? Assume that the hole is small enough that the height of the water in the cup doesn’t change significantly over the time that you make the measurements, and assume that you can neglect viscosity.

8. (4 pts) \textit{Now let\textquotesingle s test this out}: Find a paper or Styrofoam cup — a cylindrical one would be best, but those are hard to come by. A water cup from the Cougar eat is good enough. Punch a small hole at the correct height to maximize the distance that the water will go before hitting the table. The hole should be small so that you can make your measurements before the height of the water in the cup changes appreciably, but not too small or viscosity will change your results. If you use a pencil to make your hole, you will probably do well, but you will have to watch what happens quickly before the water level in the cup drops. Now place your cup on the table and mark where you expect the water to hit the table. Put your finger over the hole, and fill the cup with water. Quickly remove your finger and note how close to your mark the water hits. (a) How close were you? (b) Now put tape over your hole and punch a new hole with is higher and try again. Did the water go further or not as far? (c) Now do the same with a hole below the optimum height. Did the water go further or not as far?

\textbf{Extra problems I recommend you work (not to be turned in)}

- An extremely precise scale is used to measure an iron weight. It is found that the mass of the weight is precisely 10 kg. If we suck all of the air out of the room and weigh the iron again, how much will our measurement change?

- Rework problem 6 but now assume that the cross section of the pipe is twice as large at the bottom than at the top.

- A lead weight is placed on one end of a cylindrical wooden log with a radius $r$. The combined mass of the log and the weight is $m$. The log is then placed in a fluid with a density $\rho$. Because of the weight, the log floats upright. (a) Show that if I push the log down from it’s equilibrium position, the log will undergo harmonic motion. (b) What will the period of the motion be? Use the letter $g$ to represent the acceleration due to gravity. (Hints: You may need to review harmonic motion from Physics 121. To show that it will undergo harmonic motion, you simply have to show that the force on the log as a function of displacement from equilibrium has the same form as the force exerted by a spring when it is stretched or compressed from its equilibrium length.)
1. (3 pts) (a) What does it mean for two objects to be in thermal equilibrium? (b) Explain how two objects at the opposite side of the galaxy could be in thermal equilibrium.

2. (4 pts) Imagine that I invent a new temperature scale using a constant-volume gas thermometer. Let’s call it the Durfee scale. On my scale I define 0°C to be the melting point of lead and 100°C to be the boiling point of lead. Now imagine that I put a container filled with gas in thermal contact with lead at its melting point and measure a gas pressure of $5.73 \times 10^5$ Pa. Then I put it in contact with lead at its boiling point and measure a pressure of $1.93 \times 10^6$ Pa. How many degrees Durfee is absolute zero?

3. (3 pts) Your best friend read somewhere that the temperature at the core of the sun is thought to be about $1.5 \times 10^7$ Kelvin. He wants to know what that would be in Celsius. What would you tell him? Why?

4. (5 pts) I cut a round hole with a diameter of 10 cm in a piece of aluminum (at 300 K). I then cut out a circle of copper which is 10.0001 cm in diameter (also at 300K). (a) By how many degrees C would I need to heat up the aluminum in order to get the copper piece to fit into the hole? (b) How many degrees C would I need to cool down the copper in order to get it to fit in the hole? (c) If I start with both pieces at room temperature and then turn up the thermostat and heat up the room and everything in it, including the both pieces of metal, how much do I need to heat up the room to get the copper to fit in the hole in the aluminum?

5. (6 pts) If I push on an object from all sides, it will compress a little bit. The amount it will compress by is given by the bulk modulus $B$. If it takes a pressure increase of $\Delta P$ to reduce the volume of an object from $V$ to $V + \Delta V$ (where $\Delta V$ is negative because the object is getting smaller), the bulk modulus is defined as

$$B = \frac{-\Delta P}{\Delta V/V}.$$  

Imagine that I make a copper sphere and embed it in a block of some super material which has an extremely high bulk modulus and a linear thermal expansion coefficient of $1.1 \times 10^{-5} \degree C^{-1}$. Assume that the sphere is in contact with the block at all points on its surface. Assume that the sphere is a perfect fit for the cavity in the block — it’s a really snug fit, but the copper is not being compressed by the block. I then heat the block and the copper inside of it by $20\degree C$. With what pressure will the copper push on the block? The linear thermal expansion coefficient for copper is $1.7 \times 10^{-5} \degree C^{-1}$ and the bulk modulus of copper is $1.4 \times 10^9$ N/m$^2$.

6. (4 pts) (a) The specifications on a particular scuba diving air tank says that it should be filled to a pressure of 4350 psi (= 295.9 atmospheres). It also claims that the volume of air that it holds is 105.2 cubic feet, but what they really mean is that the air that it holds at 4350 psi, if expanded at the same temperature until it was at atmospheric pressure, would fill 105.2 cubic feet. What is the actual volume of the tank (in cubic feet)? (b) If the average mass of the molecules in the air is $4.81 \times 10^{-20}$ kg, how much does the mass of the tank change when it is pressurized from 1 atmosphere to 295.9 atmospheres at 25$\degree$C?

7. (3 pts) Consider a helium balloon. The gas in the balloon is always at a pressure which is just barely above the ambient pressure — the rubber isn’t very strong, so it can’t hold the gas if its pressure is much more than the pressure of the air around it. Imagine that I have a spherical balloon which is 10 cm in diameter. I let it go on a day when the temperature of the air is 300 K. It floats way up into the air to a point where the pressure of the atmosphere is 2/3 of what it is on the surface of the Earth. At this location the temperature of the air is just 270 K. Assuming that the air in the balloon is always at the same pressure and temperature as the surrounding air, what is the diameter of the balloon when it is at this altitude (assuming it hasn’t popped).

Where did the equation for thermal expansion come from anyway? Remember, we didn’t “derive” it in class, but we argued that it must be true for small temperature changes. So in the next problem we’ll make sure you really understand the logic we used.
8. (2 pts) The number of molecules of oxygen $N$ dissolved in a glass of water depends on the volume of water $V$ in the glass. For example, if I had twice as much water, this is equivalent to having two glasses of water, so I would expect to have twice as many oxygen molecules dissolved in the glass. The number also depends linearly on the pressure of the air $P$ around the water. If I double the pressure, I double the amount of oxygen dissolved in the water. The number also depends on temperature, but in a more complicated way. Using the same logic we used to come up with the equation for thermal expansion, write down an equation for the change in the number of dissolved molecules, $\Delta N$, as the temperature changes by a small amount $\Delta T$. This equation should be a function of $V$, $P$, $\Delta T$, and an “experimentally determined” constant $\xi$.

Extra problems I recommend you work (not to be turned in)

- Imagine now that a copper ball with a diameter of 1 cm is embedded in a block of steel such that there is no gap between them. The steel ball is embedded in a block of something with a really high bulk modulus and a really low thermal expansion coefficient. I then heat the block up by 20°C. If the bulk modulus of steel is $6 \times 10^{11} \text{N/m}^2$ and the bulk modulus of copper is $14 \times 10^{11} \text{N/m}^2$, how much will the volume of the ball change by?

- Sometimes parts are assembled and held together by making one part a little too big to fit into the hole of the other part, and then heating or cooling one of the parts and sliding them together. They then come into equilibrium and bind tightly. Imagine that you want to drill a hole in a copper plate and then use this technique to bind it to a copper rod which is precisely 2 cm in diameter. If we are going to insert the rod into the plate when the plate is at room temperature (300 K) and the rod is at the temperature of liquid nitrogen (77.2 K), what is the minimum diameter that we should make the hole?

- In our vacuum chamber in the underground lab we typically obtain pressures lower than $10^{-6}$ Pa. At this pressure, how many atoms are there per cubic cm?

- The volume expansion coefficient for mercury is $1.82 \times 10^{-4} \text{C}^{-1}$. So how can the mercury level in a mercury thermometer go from almost one edge of the tube to almost all the way to the other when the temperature changes by less than 100°C?
1. (4 pts) Your water heater is broken, so you plan to heat your bath water by hoisting buckets of water up really high, and then tipping the buckets so that the water falls down into the bathtub, converting the water’s potential energy into heat. If you want to increase the temperature of the water by 15 °C, how high will you have to lift the buckets?

2. (5 pts) Imagine an ideal aluminum calorimeter with a mass of 150 g (i.e. an aluminum cup with a mass of 150 g which is thermally isolated from the rest of the world). The calorimeter contains 200 g of water in thermal equilibrium with the calorimeter at a temperature of 25 °C. I then heat an 80 g piece of an unknown metal to a temperature of 100 °C and then drop it into the calorimeter. The system comes into thermal equilibrium at a temperature of 27.32 °C. (a) What is the specific heat of the metal? (b) From the table in your book, determine what the metal is.

3. (5 pts) An aluminum calorimeter with a mass of 125 g contains 200 g of water at 25 °C. I then drop in a 150 g cube of ice at −12 °C. (a) How much ice will be left when the system reaches thermal equilibrium, and (b) what will the temperature of the system when it reaches equilibrium?

4. (5 pts) An aluminum calorimeter with a mass of 125 g contains 200 g of water at 25 °C. I then drop in a 150 g cube of ice at −72 °C. (a) How much ice will be left when the system reaches thermal equilibrium, and (b) what will the temperature of the system when it reaches equilibrium?

5. (4 pts) A 20 kg iron shell from a tank goes off course and lands in a frozen lake. If the shell is moving at 400 m/s and is at a temperature of 35 °C when it hits the 0 °C ice, how much ice will melt?

6. (7 pts) The following may or may not work out well, depending on your microwave, etc. If it does work, you will get a wonderful feeling of awe for the power of physics. If it doesn’t, it’s still a good exercise and it will help you understand the frustrations of an experimental physicist. As long as you do the calculations correctly, the grader will be sympathetic if your experimental results aren’t so good.

Get a microwave, a watch, a pencil, a microwave safe container, a measuring cup, water, and several pieces of ice. If you don’t have a measuring cup, use the conversion factors on the next page and use a drinking cup as a measuring cup. Note that if you don’t have a microwave there are microwaves in the Wilkinson center and on the overlook above the Pendulum Court in the ESC. If you don’t have ice, you could probably get some from the drink machines in the Wilkinson center.

Put some ice into the microwave safe container and the measuring cup, and then fill them with water. Stir the water with the pencil for several minutes until the water and ice are in equilibrium (if all of the ice melts, add more). Since ice melts at 0 degrees Celsius, and water freezes at 0 degrees Celsius, we know that water and ice in equilibrium will be at zero degrees. Now remove the ice from the measuring cup, and pour water from the microwave safe container into the measuring cup until you reach the desired volume of water (you choose the volume, but I would suggest something near 1 cup). Pour out the remainder of the water in the microwave safe container. You now have a known volume of water at a temperature of about 0 degrees Celsius. Quickly pour this water in the microwave safe container and put it into the microwave on high. With your watch measure the time it takes for the water to boil (when the water starts to boil, it is at 100 degrees Celsius).

(a) Derive a symbolic expression for the heating power of the microwave, \( P \), in terms of the volume \( V \) and density \( \rho \) of water, the temperature change \( \Delta T \), the time to make this temperature change \( t \), and the specific heat of water \( c \).

(b) Plug in the numbers and determine the heating power of your microwave (in Watts).

(c) Derive a symbolic expression for the time required to melt a piece of ice with volume \( V \), density \( \rho \), and latent heat \( L \) in a microwave with heating power \( P \).
(d) Measure as best as you can the volume of an ice cube, then put it into the container. Now microwave on high and measure how long it takes to melt the ice cube.

(e) Given the measured volume of your ice cube and the measured heating power, what time does the expression you derived in part (c) predict.

The density of water is 1000 kg/m$^3$. The density of ice is 971 kg/m$^3$. The specific heat of water is 4186 J/kg°C. The latent heat of fusion for water is $3.33 \times 10^5$ J/kg.

Conversion Factors 1 liter = $10^{-3}$ m$^3$, 1 cup = .240 liter, 1 fluid oz = 0.0296 liters, 1 pint = 16 fluid oz. 1 quart = 32 fluid oz

**Extra problems I recommend you work (not to be turned in)**

- Most electrical outlets in newer homes can deliver a maximum power of about 1800 Watts. Using this much power, how long would it take to heat up a bathtub containing 0.4 m$^3$ of water from 25°C to 35°C?

- If I have an insulated container of negligible mass which contains 200 g of water at 25°C, how much ice at a temperature of $-10°C$ would I have to add such that when the system reached thermal equilibrium I would actually end up with more ice in the cup than the amount that I added?
1. (5 pts) An ideal gas is held in a thin-walled elastic container which can stretch and increase its volume as the gas is heated. It stretches in such a way that the pressure of the gas is always equal to $AV^{1/2}$ where $V$ is the volume of the gas and $A$ is a constant. The gas has an initial volume of 0.1 m$^3$ and a pressure of $1.013 \times 10^5$ Pa. The gas is then slowly heated until its pressure is $2.211 \times 10^5$ Pa. (a) What is the constant $A$? (b) How much work is done by the gas as it expands? (c) How much work is done by the atmosphere around the container as the gas inside the container expands? (hint, the work done by the atmosphere should be negative, since the volume of the atmosphere is decreasing as the container expands) (d) You should have found that the gas did more work than the atmosphere absorbed. Where did the rest of the energy go?

2. (10 pts) An ideal gas is contained inside a cylinder with a moving piston on the top. The piston has a mass $m$ which keeps the gas at a pressure $P_0$. The initial volume of the gas is $V_0$. For this whole problem give your answers in terms of $P_0$ and $V_0$.

(a) The gas is heated until the volume has expanded to twice its initial volume. How much work is done on the gas do during this process?
(b) By what factor does the temperature increase during this expansion?
(c) The piston is then locked in place and the gas is cooled back to its original temperature. What is the pressure of the gas after it is cooled?
(d) How much work is done on the gas as it is cooled?
(e) The cylinder is then placed in a bucket of water which keeps the temperature constant (at the original temperature), and the piston is released and allowed to slowly drop until the gas returns to its initial pressure $P_0$. How much work is done on the gas during this process?
(f) Draw a $P-V$ diagram of this sequence of processes. Label the initial state of the gas $A$, the state after expanding $B$, and the state after it is cooled $C$.

3. (10 pts) An ideal gas is initially at atmospheric pressure with a volume of 0.3 m$^3$.

(a) The gas is then heated at constant volume until the pressure doubles. During this process 1,200 Joules of heat flow into the gas. How much work does the gas do? (Note, unlike the last problem, I've asked you how much work the gas does rather than how much work is done on the gas. Remember that the two quantities differ by a minus sign.)
(b) What is the change in the internal energy of the gas as it is heated?
(c) Now the pressure of the gas is kept at 2 atmospheres and the gas is heated while its volume increases to twice its initial volume. In the process the internal energy of the gas increases by 1,000 Joules. How much work does the gas do?
(d) How much heat flows into the gas during the expansion?
(e) Draw a $P-V$ diagram of this sequence of processes. Label the initial state of the gas $A$, the state after the constant volume process $B$, and the state after the constant pressure process $C$.
(f) Show that the total work done by the gas through both processes is equal to the area under the curve in the $P-V$ diagram.

4. (5 pts) A 10 cm$^3$ piece of copper is heated from a temperature of 25 °C to a temperature of 35 °C. (a) How much work does the copper do on the atmosphere as it is heated? (b) How much heat does the copper absorb? (c) How much has the internal energy of the copper changed by?

Extra problems I recommend you work (not to be turned in)

- Work a bunch of the section 20.5 and 20.6 problems from the textbook.
1. (3 pts) The ground temperature for coastal cities varies less than the ground temperature of inland cities. Why?

2. (3 pts) (a) If two objects are at the same temperature, do they contain the same amount of thermal energy? Why or why not? (b) If two objects have the same mass and are at the same temperature, do they contain the same amount of thermal energy? Why or why not?

3. (4 pts) I have two solid bars with a square cross section. Both have a cross section of 1 cm², and both are 30 cm long, but one is made of copper and one of iron. I place the two side by side and braze them together, making a composite bar which is 30 cm long with a cross section of 2 cm². I then place one end of this rod in boiling water and one end in ice water. How much power will be conducted through the rod when it reaches steady state?

4. (7 pts) Hot water from my water heater passes through a section of insulated pipe. The pipe is made of iron with an inner diameter of 1 cm and an outer diameter of 1.3 cm. The pipe is then surrounded by a thin layer of rubber out to a diameter of 1.4 cm. Assuming that the water is flowing quickly enough that the temperature of the water is always 40 °C and that the outer surface of the rubber is always at 25 °C, (a) what is the difference in the temperature of the water and the temperature at the iron/rubber interface, and (b) how much power flows out of a section of pipe which is 2 meters long? Hint: you have to integrate.

5. (4 pts) A typical 100 Watt incandescent bulb has a filament which is at a temperature of 3000 K. Typically, of the 100 W that goes into the bulb, 98 W is conducted or convected away and only about 2 W is radiated as light (and most of that is invisible infrared light — now you see why incandescent lights are so inefficient). (a) If we assume the emissivity of the tungsten filament in such a bulb is 0.5, what is the surface area of the filament in a typical 100 W bulb? (b) If we could raise the temperature we would expect that the losses due to conduction and convection to go up by about the same factor as the temperature increase. But blackbody radiation scales as $T^4$. If we increase the temperature of the filament by 50% to 4500 K, by what factor will the light output increase? Unfortunately, if the filament gets too hot, it will melt or vaporize. This is why almost all incandescent bulbs run at about the same temperature - as hot as possible without quickly destroying the tungsten filament. This is also the secret to Halogen bulbs — the halogen gas in the bulb reduces the rate at which the tungsten evaporates from the filament, allowing them to operate at higher temperatures for more brightness and efficiency.

6. (5 pts) The intensity of the light from the sun a the radius of the Earth’s orbit is 1340 W/m². Assuming that the emissivity of the Earth is the same for all wavelengths of light, calculate the temperature of the Earth in steady state. You should get something very cold. The reason that the Earth is not this cold is due to the fact that the emissivity of the Earth depends strongly on wavelength due to the so-called “greenhouse effect.” Because of the atmosphere, the Earth absorbs and emits visible radiation better than infrared radiation. Since the sun is very hot, it emits a lot of visible light which is absorbed by the Earth. Since the Earth is much colder it emits mostly infrared light. The clouds are very reflective in the infrared, so the emissivity is small right where the Earth would be radiating most of its blackbody radiation otherwise. On the moon, however...

7. (4 pts) The wall of a house is 10 feet tall by 25 feet wide. It is made of a 4 inch layer of brick followed by a 3.5 inch layer of fiberglass batting which is covered by a 0.5 inch sheet of drywall. (a) What is the $R$ value for the wall (in ft²·°F·h/Btu)? Don’t forget about the stagnant air layer on both sides of the wall. (b) How much power (in Btu/hr) will be flowing through the wall if the inside air is at a temperature of 62°F and the outside air is at a temperature of 0°F. (c) How many Watts is that? (One Btu = 1054 J).

**Extra problems I recommend you work (not to be turned in)**

- Imagine a copper rod which is 1 cm in diameter and 10 cm long. One end of the rod is kept at 0°C and the other is heated with a torch. How hot do we have to get the end of the rod before the power radiated by the rod is 0.1% of the power conducted through the rod?
- I have two solid round bars which are 1 cm in diameter. One, made of copper, is 20 cm long. The other, made of iron, is 10 cm long. I braze one end of the copper bar to one end of the iron bar to make a bar with a combined length of 30 cm. I then place the very tip of the copper end of the bar in a pot of ice water and the very tip of the iron end in a pot of boiling water. (a) When the bar has reached “steady state,” what will the temperature be at the junction between the iron and the copper? (b) How much power will be conducted through the rod?

- Now consider many rods made of different materials brazed end to end. Prove that we can solve this problem by adding $R$ values.

- Imagine a spherical ball with emissivity $\epsilon_1$ suspended at the center of a spherical vacuum chamber with emissivity $\epsilon_2$. Show that if and only if the ball is at the same temperature as the chamber, the rate at which it emits blackbody radiation will be equal to the rate at which it absorbs radiation.

- Put something plastic and something metal somewhere where they will get significantly hotter or colder than room temperature. Let them come into thermal equilibrium. (a) What did you choose and where did you put them? (b) Which one will feel “hottest”/”coolest” if you pick it up? (c) Why? (d) Try it. Were you correct? Note: on a day which is very sunny (or cold) you simply find a metal and plastic object which has been outside for a long time (like a plastic sign on a metal sign post).

- A cylindrical insulating bucket is filled with water at 0 °C. The air above the water has a temperature of −12 °C. If the air remains at this temperature, how long will it take for a 1 cm layer of ice to form on the surface of the water?