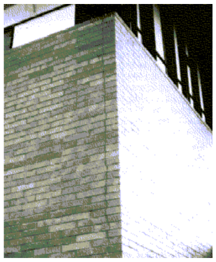
Physics 121, April 15, 2008.
Temperature/Heat and the Ideal Gas Law.



http://www.brickinfo.org/BIA/technotes/t18.htm

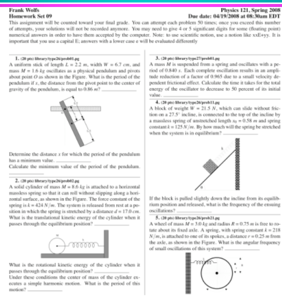
Physics 121.
April 15, 2008.

- Course information
- Topics to be discussed today:
  - Temperature (review).
  - The universal gas law.

Physics 121.
April 15, 2008.

- Homework set # 9 is now available and is due on Saturday morning, April 19, at 8.30 am.
- Midterm Exam # 3 will take place on Tuesday April 22 between 8.00 am and 9.30 am in Hubbell. The material to be covered is the material contained in Chapters 10, 11, 12, and 14.
- There will be extra office hours on Sunday and Monday. Details will be announced via email.

Homework set # 9.
All about simple harmonic motion.


Frank Wolfs — **Physics 121, Spring 2008**
Homework Set 09 — **Due date: 04/19/2008 at 08:30am EDT**

This assignment will be counted toward your final grade. You can attempt each problem 50 times; once you exceed this number of attempts, your solutions will not be recorded anymore. You may need to give 4 or 5 significant digits for some (floating point) numerical answers in order to have them accepted by the computer. Note: to use scientific notion, use a notion like xxE+yy. It is important that you use a capital E; answers with a lower case e will be evaluated differently

1. (20 pts) library/type26/prob01.pg
A uniform stick of length $L = 2.2\ m$, width $W = 6.7\ cm$, and mass $M = 1.6\ kg$ oscillates as a physical pendulum and pivots about point O as shown in the Figure. What is the period of the pendulum if x, the distance from the pivot point to the center of gravity of the pendulum, is equal to 0.86 m? ________

Determine the distance x for which the period of the pendulum has a minimum value. ________
Calculate the minimum value of the period of the pendulum. ________

2. (20 pts) library/type26/prob02.pg
A solid cylinder of mass $M = 8.6\ kg$ is attached to a horizontal massless spring so that it can roll without slipping along a horizontal surface, as shown in the Figure. The force constant of the spring is $k = 424\ N/m$. The system is released from rest at a position in which the spring is stretched by a distance $d = 17.0\ cm$. What is the translational kinetic energy of the cylinder when it passes through the equilibrium position? ________

What is the rotational kinetic energy of the cylinder when it passes through the equilibrium position? ________
Under these conditions the center of mass of the cylinder executes a simple harmonic motion. What is the period of this motion? ________

3. (20 pts) library/type27/prob01.pg
A mass M is suspended from a spring and oscillates with a period of 0.840 s. Each complete oscillation results in an amplitude reduction of a factor of 0.965 due to a small velocity dependent frictional effect. Calculate the time it takes for the total energy of the oscillator to decrease to 50 percent of its initial value. ________

4. (20 pts) library/type26/prob11.pg
A block of weight $W = 21.5\ N$, which can slide without friction on a 27.5° incline, is connected to the top of the incline by a massless spring of unstretched length $x_0 = 0.58\ m$ and spring constant $k = 125\ N/m$. By how much will the spring be stretched when the system is in equilibrium? ________

If the block is pulled slightly down the incline from its equilibrium position and released, what is the frequency of the ensuing oscillations? ________

5. (20 pts) library/type26/prob21.pg
A wheel of mass $M = 3.0\ kg$ and radius $R = 0.75\ m$ is free to rotate about its fixed axle. A spring, with spring constant $k = 218\ N/m$, is attached to one of its spokes, a distance $r = 0.25\ m$ from the axle, as shown in the Figure. What is the angular frequency of small oscillations of this system? ________

Generated by the WeBWorK system ©WeBWorK Team, Department of Mathematics, University of Rochester

In all cases:
$a = -\omega^2 x$

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

Temperature (a quick review).
Measuring temperature.

- In order to measure temperature we must:
  - Agree on a standard reference point to which we assign a certain temperature.
  - Agree on a unit.
  - Agree on a standard thermometer against which all other thermometers can be calibrated.
- The unit of temperature will be the Kelvin (K).
- The standard reference point is the triple point of water (T = 273.16 K).

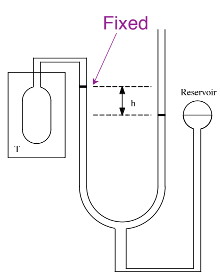
http://www.fluke.fr/common/prod_pages/pages/hart/products/tpw.htm

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

Temperature (a quick review).
Measuring temperature.

- The standard thermometer is the constant volume gas thermometer.
- The bulb of the thermometer, which is filled with gas, is put in thermal contact with the system to be studied.
- The reservoir on the right is now adjusted to change the mercury level so that the gas volume remains unchanged.
- The temperature of the body is defined in terms of the pressure p:

$$T = Cp = C(p_0 + \rho g h)$$



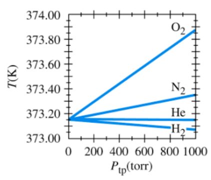
Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

Temperature (a quick review). Measuring temperature.

- In general we can thus find the temperature of the body by comparing the measured pressure with the triple-point pressure:

$$T = T_3\,(p/p_3) = 273.16\,(p/p_3)$$

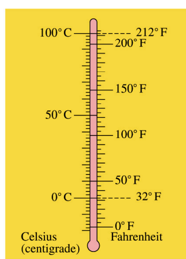
- The method described here depends slightly on the amount and the type of gas in the bulb. However, this dependence is reduced when we use smaller and smaller amounts of gas.



Temperature (a quick review). Measuring temperature.

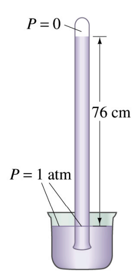
- The Kelvin is not frequently used in our daily life.
- More common temperature scales are the Celsius scale:
  - 0° is defined as the freezing point of water.
  - 100° is defined as the boiling point of water.

  and the Fahrenheit scale:
  - 0° was defined as the temperature of a mixture of water, ice, and ammonium chloride.
  - 96° was as the temperature of the blood of Fahrenheit's wife.
  - Note: initially Fahrenheit divided his scale in 12 segments; later he divided each segment in 8 smaller segments.



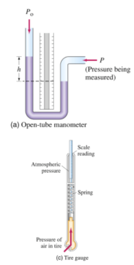
Thermodynamic variables. Pressure.

- Pressure is an important thermodynamic variable.
- Pressure is defined as the force per unit area.
- The SI unit is pressure is the Pascal: 1 Pa = 1 N/m^2. Another common unit is the atm (atmospheric pressure) which is the pressure exerted by the atmosphere on us (1 atm = 1.013 x 10^5 N/m^2).
- A pressure of 1 atm will push a mercury column up by 76 cm.

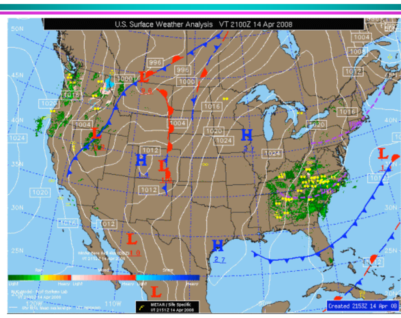


Thermodynamic variables. Pressure.

- Many devices that measure pressure, actually measure the pressure difference between the pressure of interest and the atmospheric pressure.
- Atmospheric pressure changes with altitude. The higher you go, the less air is pressing on your head! Airplanes use the atmospheric pressure to measure altitude.
- But keep into consideration that the atmospheric pressure at a fixed location and altitude is not constant!



Thermodynamic variables. Pressure.

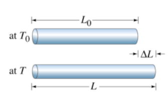


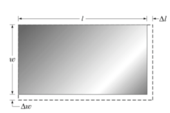
Thermal expansion. Linear expansion.

- When the temperature of a material increases, its length will increase:

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

- The coefficient α is the coefficient of linear expansion. Typical values are 0.5 x 10^{-6} K^{-1} and 10 x 10^{-6} K^{-1} at room temperature.
- Note: a solid will expand in every direction!!!!!





Thermal expansion. Linear expansion.

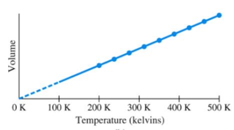
- In everything we design we need to consider the effects of thermal expansion:
  - Draw bridges must be able to open in summer and winter.
  - Airplanes expand in flight due to friction with the air! The width of the Concorde increases by a few cm during its flight.

Thermal expansion. Volume expansion.

- When we deal with liquids we usually talk about volume expansion:

$$\Delta V = \beta V \Delta T$$

- The coefficient β is the volume expansion coefficient.
- The coefficient of volume expansion β is related to the coefficient of linear expansion α.



Relation between volume and linear expansion.

- Consider a volume V whose temperature is increased by ΔT:

$$\Delta V = (L+\Delta L)(W+\Delta W)(H+\Delta H) - LWH =$$

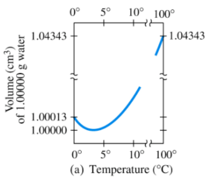
$$= WH\Delta L + LH\Delta W + WL\Delta H =$$

$$= V\left(\frac{\Delta L}{L} + \frac{\Delta H}{H} + \frac{\Delta W}{W}\right) = V(3\alpha\Delta T)$$

- We see that $\beta = 3\alpha$.

Volume expansion. The water anomaly.

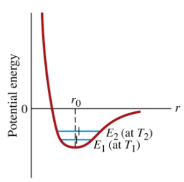
- Water has a very different thermal behavior from other liquids. It expands when it is cooled below 4°C.
- Its expansion continues even below the freezing point (frozen pipes). This is why ice cubes float!
- The anomalous behavior of water effects the way bodies of water freeze:
  - The body of water will cool down until it has a uniform temperature of 4°C.
  - Ice will form on top (life continues below).



Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

Volume expansion. A microscopic view.

- The atoms in a solid are held together in a three-dimensional periodic lattice by spring-like interaction forces. The potential energy for a pair of neighboring atoms depends on their separation r, and has a minimum at $r = r_0$. The distance r_0 is the lattice spacing of a solid when the temperature approaches zero. The potential energy curve rises more steeply when the atoms are pushed together ($r < r_0$) than when they are pulled apart ($r > r_0$). The average separation distance at a temperature above the absolute zero will therefore be larger than r_0. **A solid with a symmetric potential energy curve would not expand.**



Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

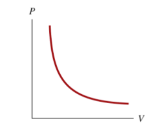
The equation of state of a gas.

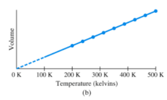
- Thermal expansion of a gas is more complicated then thermal expansion of solids or liquids.
- The volume taken up by a gas is usually equal to the volume that is available.
- The volume expansion theory we just discussed applies only to a gas if its pressure is kept constant.
- In order to state of a gas, we need to specify its temperature, its volume, and its pressure. The relation between these variables and the mass of the gas is called **the equation of state**.

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

The equation of state of a gas.

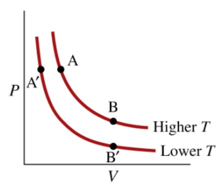
- The equation of state of a gas was initially obtained on the basis of observations.
  - Boyle's Law (1627 - 1691): ***PV* = constant** for gases maintained at constant temperature.
  - Charle's Law (1746 - 1823): ***V*/*T* = constant** for gases maintained at constant pressure.
  - Gay-Lussac's Law (1778 - 1850): ***P*/*T* = constant** for gases maintained at constant volume





The equation of state of a gas.

- Combining the various gas laws we can obtain a single more general relation between pressure, temperature, and volume: $pV \propto T$
- Another observation that needs to be included is the dependence on the amount of gas: if pressure and temperature are kept constant, the volume is proportional to the mass m: $pV \propto mT$



The equation of state of a gas.

- The equation of state of a gas can be written as

$$pV = nRT$$

where
  - p = pressure (in Pa).
  - V = volume (in m^3).
  - n = number of moles of gas (1 mole = 6.02 x 10^{23} molecules or atoms). Note the number of molecules in a mole is also known as Avogadro's number N_A.
  - R = the universal gas constant (R = 8.315 J/(mol K).
  - T = temperature (in K).
- Note: the equation of state is the equation of state of an ideal gas. Gases at very high pressure and/or close to the freezing point show deviations from the ideal gas law.

The equation of state of a gas. Example problem.

- A cylinder contains oxygen at 20°C and a pressure of 15 atm at a volume of 12 l. The temperature is raised to 35°C , and the volume is reduced to 8.5 l. What is the final pressure of the gas?
- Since the amount of gas does not change, we can rewrite the ideal gas law in the following way: pV/T = constant. Since we know the initial state, we can determine the missing information about the final state:

$$p_i V_i / T_i = p_f V_f / T_f$$

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

The equation of state of a gas. Example problem.

- The final pressure of the gas is equal to

$$p_f = p_i (V_i/V_f) / (T_i/T_f)$$

- Note:
  - This relation will preserve the units of pressure.
  - The units of volume cancel, and we can keep the volume in units of liters. Note: for whatever we unit we choose, zero volume in SI units, correspond to zero volume in all other units.
  - The units of temperature must be in Kelvin. The temperature ratio T_i/T_f = (273.15 + 20)/(273.15 + 35) = 0.951 when T is expressed in Kelvin. The ratio would be 0.571 when T is expressed in Celsius.
- When we use the correct units, we find that p_f = 22 atm.

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

Done for today! On Thursday: The Kinetic Theory of Gases.

Facing NGC 6946 Credit & Copyright: Robert Gendler

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester