H A&S 222d/253e Introduction to Energy and Environment:
Life Under the Pale Sun
P.B.Rhines, J.Wright
Spring 2007
Lecture 5 THERMAL ENERGY

SCIENCE CORE: PHYSICS OF ENERGY, continued

We are beginning to fill in the list of 'forms of energy' and to give examples of the magnitudes...the amounts...of energy present in familiar objects. The kinetic energy in a 1 kg. rock moving at 1 meter/sec is ½ Joule. As shown earlier, Ch. 2 sec. 2.11, a flowing river can contain a large kinetic energy by virtue of its size...its mass (although there it makes sense to consider the power flowing past an observation point on the river, as well as the kinetic energy per kg. of water). We will see again that thermal energy is 'rich', or concentrated and chemical energy is even more so.

THERMAL ENERGY AND THE HEAT ENGINE

Thermal energy…'heat'…can be transformed into mechanical energy or vice-versa. Heat can move by radiating light or invisible, infrared radiation. But some aspects of thermal energy are quite simple. Earlier we introduced the 1st law of thermodyamics, and mentioned the idea of an engine that produces mechanical energy by converting some thermal or chemical energy. If you squeeze a gas it becomes warmer…instantly. This happens because 'squeezing' means exerting a force and changing the volume of gas. Recall that exerting a force on a moving object requires *work* in the amount:

work = force x distance traveled….Joules

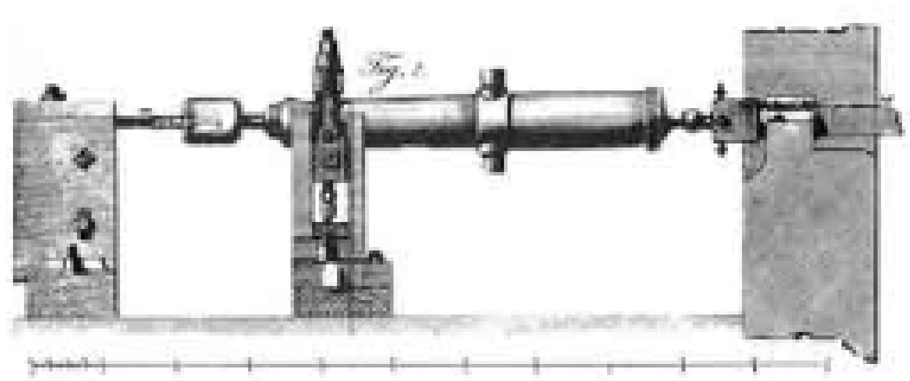
and this corresponds to: power = force x velocity of the moved object … Watts.
This is equal to the change in energy of the moving object. In our case the object is the gas, and compressing it requires work, and the work goes into internal heat energy of the gas: it warms up. Thinking of a gas like air as billiard-ball like molecules flying around, bouncing off each other and bouncing off the walls of their container, you can imagine that squeezing the gas could make the molecules move faster. We can illustrate this by squeezing the air in a spherical glass vessel, measuring the increase in pressure, and seeing the temperature rise (for example, by the change in color of a liquid crystal thermometer). {elaboration: When you hit a tennis ball with a racquet, the speed of the ball is greatly increased. Now think of a billiard ball bouncing off a wall. If no energy is lost (the collision is called 'elastic'), then the speed of the ball perpendicular to the wall after rebounding, U_2, is the same as before rebounding, U_1, yet in the opposite direction: $U_2=U_1$. If, instead, the wall is moving steadily toward the ball before the collision, then the ball's rebound speed will be greater, $U_2 = U_1 + 2\,U_{wall}$. We can see why by imagining that we are riding with the moving wall. In this frame of reference, the ball bounces simply, conserving its velocity which is U_1+U_{wall} both before and after the collision. An observer not riding on the moving wall thus sees speeds U_1 and $U_1 + 2U_{wall}$ before and after the collision. }

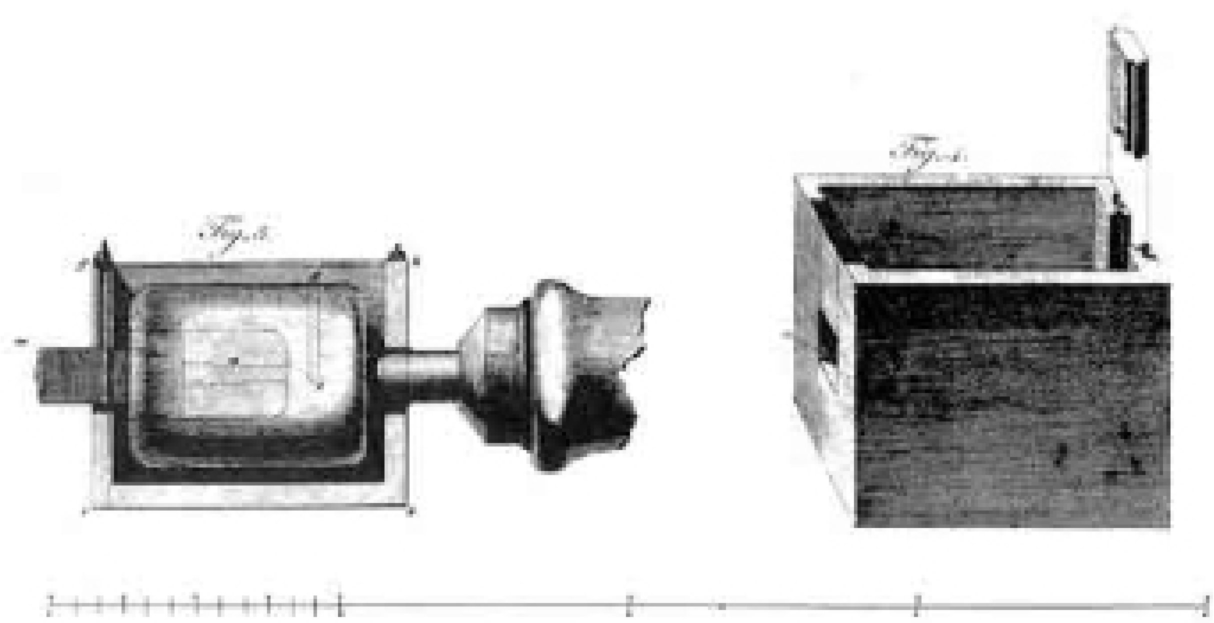
In the 1st Law of Thermodynamics, that is the thermal energy equation,

$$\Delta E_{int} = \Delta' Q + \Delta' W$$

where E_{int} is the **internal, thermal energy** of the gas. We just described an event where the internal energy change (left-hand side) was produced by **work done** by squeezing, Δ'W, which is equal to -PΔv, or the product of pressure P and the change in volume, v. The middle term, Δ'Q is the **heating**, for example by a candle, which was not active. In the simple case above, P (force per unit area) multiplied by Δv (change in volume of gas) is the same as force multiplied by distance traveled. Check the units: force per square meter times volume change in cubic meters, or $(force/m^2) \times m^3 = force \times m$.

Benjamin Thompson, Count Rumford (1753-1814) invented fireplaces, gunpowder and the relation between heat and mechanical energy (and fierce loyalty to the British King). The device below was designed to observe the heating that occurs when a cannon barrel is bored out of a block of metal. The lathe was driven by a horse I believe. This established that thermal energy…'heat'… was not a mysterious substance (called 'caloric') but could be produced from mechanical energy..through the 'work' term in the first law of thermodynamics above.





The idea of temperature. Temperature arose as an intuitive feeling, and it was then noticed that some clear physical events correspond well to this feeling. The height of a column of mercury or alcohol, for example, provides a useful scale that seems about right. In this way temperature could be measured. The expansion of a material as it is warmed can be analyzed in the simplest case: an *ideal gas*. This perhaps should be called 'idealized gas'. It is a model of a real gas based on having molecules far apart (a 'dilute gas') and simplifying their collisions as being those of billiard balls; no energy loss (known as 'elastic collisions'). The *kinetic molecular theory* (KMT) for this gas provides a theoretical model of the distribution of velocity among the molecules. In doing so it relates their kinetic energy to the pressure that is felt on the walls containing the gas. Working models illustrating the KMT model of a gas can be found at
http://comp.uark.edu/~jgeabana/mol_dyn/KinThI.html

http://www.chm.davidson.edu/Chemistry/Applets/KineticMolecularTheory/BasicConcepts.html

Of great importance, the Kinetic Molecular Theory gives a physics-based definition of *temperature, T, such that T is proportional to the kinetic energy of molecules making up an ideal gas.* And, *what we call thermal energy is the kinetic energy of molecules of an ideal gas.* Yet the physics definition and the intuitive sense of temperature have to be reconciled. Temperture as we experience it came to be associated with the expansion of solids and liquids…mercury or alcohol in a glass tube became a thermometer. The marvelous thing is that these two different ideas of temperature agree!

Equation of state for an ideal gas. The results of the kinetic-molecular theory of gases (based on a billiard-ball model of molecules and their collisions) include an equation which connects the pressure, P, temperature, T, and volume, v, of a gas. [Don't confuse the symbol for volume v (m^3) with the speed V ($m\ sec^{-1}$)]. It grew out of