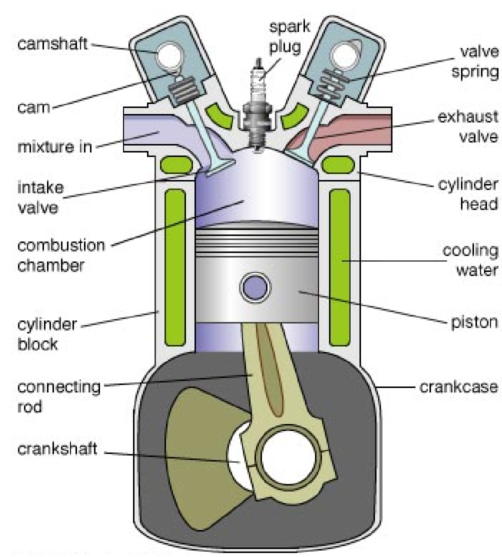
UNIT 3 THERMODYNAMICS

PHYS:1200 LECTURE 16 — THERMODYNAMICS (1)

Thermodynamics is the science dealing with the transformation of **heat energy** into **mechanical energy.** It applies to the most practical aspects of everyday life: how we use energy and how it can be transformed from one form into another. Understanding the difference between heat energy and mechanical energy is an essential aspect of thermodynamics. Suppose I have an *empty* box that contains only air molecules. The air molecules in the box are moving around with very high velocities, about 300 m/s in random directions. The motion of the molecules is completely disorganized motion called heat energy. On the other hand, if the box is pushed from one location to another, the box has organized motion called mechanical energy.

In this unit we will also discuss some of the important concepts of atmospheric physics that are behind the issue of **climate change**.

16-1. Engines.—Thermodynamics is concerned with the operation of engines**. An engine is a device which converts heat energy into mechanical energy**. To make this more concrete, consider what takes place in your car engine. You start by filling your fuel tank with gasoline. Gasoline is a substance that is capable of combustion – it can burn, which means that it can undergo a chemical reaction with oxygen. There is (chemical) potential energy stored in gasoline which is released in the combustion process. An automobile engine (*internal combustion engine*) uses the heat released when gasoline undergoes a confined explosion inside the engine *cylinders*. Most autos have 4 or 6 cylinders, and each one has a piston that is caused to move very quickly when the gas in it explodes (Maximum piston speeds of 25 m/s). The explosion is started by a spark from a *spark plug*. The explosion releases a large amount of heat which causes the molecules in the cylinder to expand very quickly causing the piston to move quickly. The

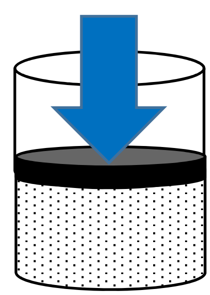


motion of the pistons is transmitted by a *connecting rod* to the *crankshaft* which then rotates at high speed. The connecting rod transfers the up and down motion of the piston to the rotary motion of the crankshaft. The rotation of the crankshaft is then transmitted (through the car's *transmission*) to the wheels which move it forward. We want to concentrate on the various motions that take place in these processes, from the motions of the molecules in the combustion products to the motion of the auto itself. Whenever a gas is heated, as in the combustion process, the kinetic energy of the molecules is increased. The motion of the molecules is very chaotic -- they move around very swiftly in all directions. We call this type of energy thermal energy – the **random kinetic energy** of the atoms or molecules. Now when the car is moving forward it also has kinetic energy, but this kinetic energy is associated with the **organized forward motion** of the auto**. So in effect, the engine is a device which uses random thermal energy to do work which results in the organized kinetic energy of the car.** The basic problem of thermodynamics is to **understand how heat or thermal energy is converted into work energy and how efficiently this can be done**. The laws of thermodynamics that we will discuss, place strong limits on how these processes occur. **We will discover that it is impossible to convert thermal motion entirely into work --- this is a law of nature**. This fact is obvious in the car engine which must have a cooling system to remove the excess heat energy that is not converted into work.

A steam engine is another example of an engine. Wood, coal, or fuel is burned and the heat is used to make steam. The steam then pushes against pistons which make the wheels turn. The human body is also an engine. We take in fuel in the form of food. Our metabolism converts this fuel into energy which we use to do work, run for example. All engines are subject to the laws of thermodynamics which we will be discussing in this unit. The performance of an engine is quantified by its efficiency defined as the ratio of its output (work) to the energy input.

16-2. Internal Energy and Temperature.—The air molecules in a container move about in random directions. Some molecules move slowly, others move more rapidly, but by virtue of the motion of a molecule, it has kinetic energy $\frac{1}{2}mv^2$. **The internal energy U of the gas of air molecules is the total kinetic energy of all the molecules in the container**. We cannot directly measure the internal energy of a gas because that would require that we simultaneously know the velocities of every molecule, and under normal conditions, there are many times 10^{23} of them in the box. However, there is a parameter that does provide a measure of the average kinetic energy of the molecules – the temperature. **The temperature of a system is a measure of the average kinetic energy of the molecules. Slide 13** provides an illustration of the difference between internal energy and temperature. The three vessels contain different numbers of molecules but the average kinetic energy of the molecules in all 3 vessels is the same so they have the same temperature.

16-3. Heat and Work.—Heat and temperature are related, although they are different physical quantities, and the distinction between them is both subtle and important. **Heat is the energy that flows from one object (system) to another object (system) because they are not at the same temperature**. Heat stops flowing when the two systems reach the same temperature. (**slide 14**). **So a flow of heat is driven by a difference in temperatures of two systems.** We will discuss the mechanisms for heat flow in the next lecture. When heat is added to a system, its temperature increases; when heat is removed from a system, its temperature decreases**. When heat is added to a system, that energy appears as an increase in the internal energy of the system, which means that the average kinetic energy of the molecules in the system increases.** Work done on a system can also increase its internal energy. For example, when two objects are rubbed together – like two pieces of wood, the friction force acting on the object does work on it**. This work energy then appears in the object as an increase in internal energy – it gets hot!** Another example is compression of a gas. The figure shows gas molecules confined in a container that has a moveable piston. If the gas is compressed by pushing down on the piston its internal energy increases, and as a result its temperature also increases. Temperature is a parameter that can be measured and reflects what is going on with the molecules which we cannot directly measure.



16-4. The Measurement of Temperature.—We will now spend some time discussing the practical aspects of how temperature is measured. **Temperature measurements are based on the observation that the properties of materials change with temperature**. We know that the temperature has changed because we see that some property of the material has changed. Various examples are listed on **slide 16**. One common method of measuring temperature is based on the fact that a column of liquid in a thin tube expands when the temperature increases and contracts when the temperature decreases—mercury (Hg) thermometers are based on this. This process is made quantitative, by associating particular lengths of the Hg column with repeatable processes like boiling or freezing of water. This is how the Celsius and Fahrenheit temperature scales were defined. This is illustrated on **slide 18**. Having more than one temperature scale requires that we have formulas to convert from one to the other. **The conversions from C to F and F to C are given by the following formulas:**

Fahrenheit to Celsius	$T_C = \frac{5}{9}(T_F - 32)$	[1a]
Celsius to Fahrenheit	$T_F = \frac{9}{5}T_C + 32$	[1b]

where T_C is the temperature in Celsius and T_F is the temperature in Fahrenheit. Notice that on these temperature scales, zero degrees is not particularly significant, except that it is the temperature at which water freezes. On both scales negative temperatures are necessary. There is another temperature scale where **zero degrees is the lowest possible temperature** – no negative temperatures. This is the **absolute temperature scale or the Kelvin (K) scale**. This is the scale used for scientific temperature measurement. The dependence of the pressure in a gas with temperature can be used as a means of measurement of absolute temperature. When all gases are cooled, their pressure decreases. The pressure vs. temperature plot (**slide 22**) for all gases extrapolates to a minimum temperature of –273.15 C. This is absolute zero, or 0K. The conversion from Celsius to Kelvin is then

Celsius to Kelvin	$T_K = T_C + 273.15.$	[2]

There are no negative temperatures on the Kelvin scale.