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Thermal Physics, Thermodynamics, and Statistical Mechanics

- Thermal physics deals with "thermodynamic systems" (collections of large numbers of atoms and molecules). Such a system has many degrees of freedom (crudely speaking, ways of storing energy).
- Thermodynamics deals with those principles and properties of bulk matter that don't really depend on the underlying microscopic details.
- Statistical mechanics takes into account the quantum behavior of atoms and the laws of statistics. This allows predictions of material properties and provides fundamental explanations of thermodynamic laws.

Temperature vs. Heat

In everyday speech, we think of the temperature as specifying "how hot" an object is, but in physics…
… temperature and heat are not the same!

- **Temperature** is a measure of the intensity of disorderly microscopic motion. (We'll be more precise later.)
- Heat transfer and performance of work are two different ways by which one part of the universe can give energy to another (without transfer of matter).
- Many physicists try to avoid using the word **heat** as a noun because there is no fundamental conservation of heat (only a conservation of energy). It's not possible to ascribe a definite "heat content" for a system.

Work

- According to the classical work-energy theorem (CWE theorem), the work done by the net force equals the change in kinetic energy of an object.
- However, it is also possible for an external agent to do work on a system (as, for example, when a piston is used to compress the gas within a cylinder) and change the system's energy content without producing translational motion or spin.
- Roughly speaking, we can think of the thermodynamic work done on a system as an energy change in the system that is not a direct consequence of any temperature difference between the system and the external agent.

Heat Transfer

- Alternatively, an external agent (or "the surroundings") can provide energy to (or take energy from) a system solely by <u>heat transfer</u>, which IS a consequence of a temperature difference between the system and its surroundings.
  - If the surroundings have a higher temperature than the system, the energy of the system increases due to heat transfer.
  - If the surroundings have a lower temperature than the system, the energy of the system decreases due to heat transfer.
- NOTE: In many (most) circumstances, thermodynamic energy transfers involve BOTH "the performance of thermodynamic work" and "heat transfer."

Thermal Contact & Thermal Equilibrium

- Two systems which are capable of exchanging energy via heat transfer are said to be in <u>thermal contact</u>. Systems that are in thermal contact but show no tendency for any heat transfer are said to be in <u>thermal equilibrium</u>.
- The Zeroth Law of Thermodynamics consists in the following experimentally confirmed statement. Given three systems A,B, and C:
  - if A is in thermal equilibrium with C
  - and B is also in thermal equilibrium with C
  - then A and B will be in thermal equilibrium with each other.

Thermometry: I

- The Zeroth Law of Thermodynamics implies that we can set up a scale (<u>temperature</u>) which governs the direction of heat transfer when two systems are placed in thermal contact: <u>When two objects are placed in thermal contact, energy is spontaneously transferred from the system at higher temperature to the system at lower temperature.</u>
- NOTE: Although the previous statement may appear obviously and trivially true, it turns out that certain (unusual) systems which can exist at negative temperatures will spontaneously transfer energy to positive-temperature systems. Thus the underlined statement is correct only for two systems that both have positive temperature.

Thermometry: II

- Practically, constructing a thermometer means identifying a <u>thermometric property</u> (some characteristic of the system that is determined by temperature). Some possible choices for the thermometric property:
  - the volume of a given mass of mercury, as indicated by the length of the column in a mercury-in-glass thermometer
  - the pressure in a sample of gas held at constant volume
  - the volume of a constant-pressure gas sample
- It is also necessary to "calibrate" any thermometer by using one or more calibration points. The Celsius scale is set by the statement that the freezing point of water (at 1 atm) is 0 ^{o}C and the boiling point of water (at 1 atm) is 100 ^{o}C.

Thermometry: III

- Using the Celsius scale, the unique temperature at which all three phases of water can exist in equilibrium is 0.01 ^{o}C. This triple point of water is actually used for a “single-point” calibration of the Celsius scale.
- It is observed that the pressure of a dilute constant-volume gas thermometer varies linearly with the temperature, with the extrapolated pressure dropping to zero at $t_{Celsius}$ = -273.15 ^{o}C.
- The ideal gas temperature scale is defined by using the same degree size as the Celsius scale, but adding 273.15 to the Celsius reading, so that a dilute constant-volume gas thermometer extrapolates to zero pressure at 0 on the new scale. This is also called the **kelvin scale**:

$$\boxed{T = t_{Celsius} + 273.15}$$

Thermal Expansion: I

- At a given pressure, most materials expand when heated.
- The coefficient of linear expansion is in principle temperature –dependent and is defined by:

$$\boxed{\alpha(T) \equiv \lim_{\Delta T \to 0} \left[\frac{\Delta \ell}{\ell \Delta T} \right]}$$

- NOTE: A single coefficient of linear expansion suffices for an isotropic material, but there are some materials which have different coefficients of expansion along different directions.

Thermal Expansion: II

- If the changes in temperature and length are relatively small, then the increase in length can be written as

$$\boxed{\Delta \ell \equiv \ell(T_i + \Delta T) - \ell(T_i) \approx \alpha(T_i)\ell(T_i)\Delta T}$$

- For isotropic materials,
  - the coefficient of area expansion = 2α
  - the coefficient of volume expansion = 3α
- Since liquids and gases have no definite shape, the only coefficient that we can define for liquids is the coefficient of volume expansion, which is often denoted by γ (rather than 3α).