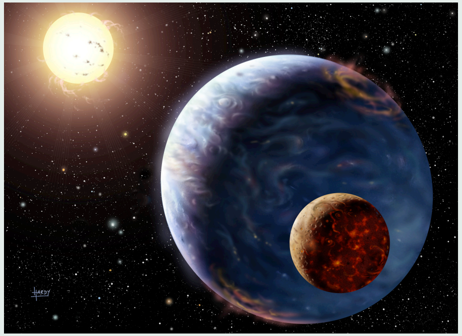
Rutgers University
Department of Physics & Astronomy

01:750:271 Honors Physics I
Fall 2015

Lecture 22

- **Planets and satellites: Kepler's 1st law**



How do objects – planets and satellites – move under gravitational force?

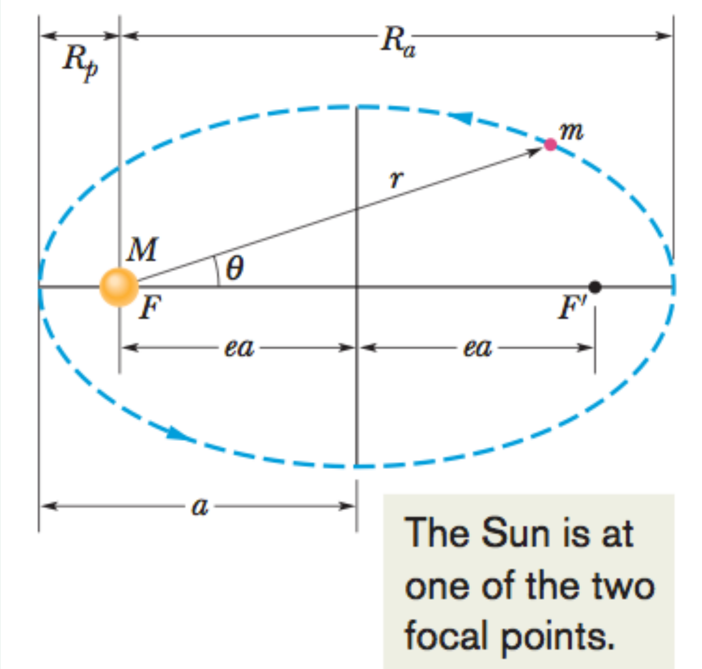
Light objects under the gravitational force of a very massive body assumed stationary (Sun or Earth).

$$M_{\text{Sun}} >> M_{\text{Planet}} \qquad M_{\text{Earth}} >> M_{\text{Satellite}}$$

COM of the system $\simeq$ COM of central body

The Law of Orbits

All planets move in elliptical orbits with the sun at one focus.



Ellipse:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \qquad (a \geq b)$$

$a =$ **(semi)major axis**

$b =$ **(semi)minor axis**

Excentricity:

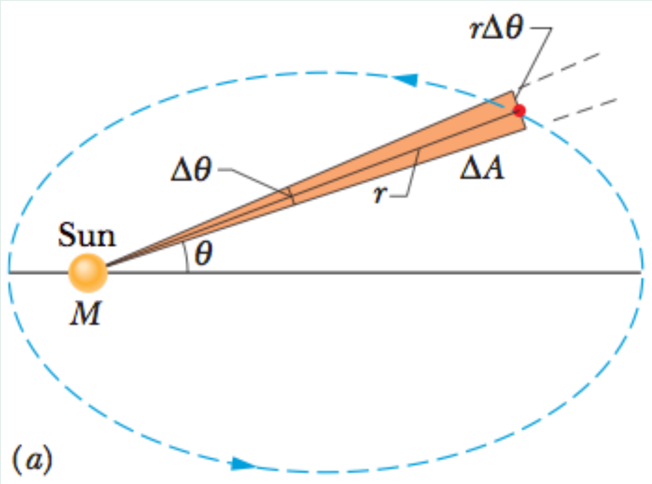
$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

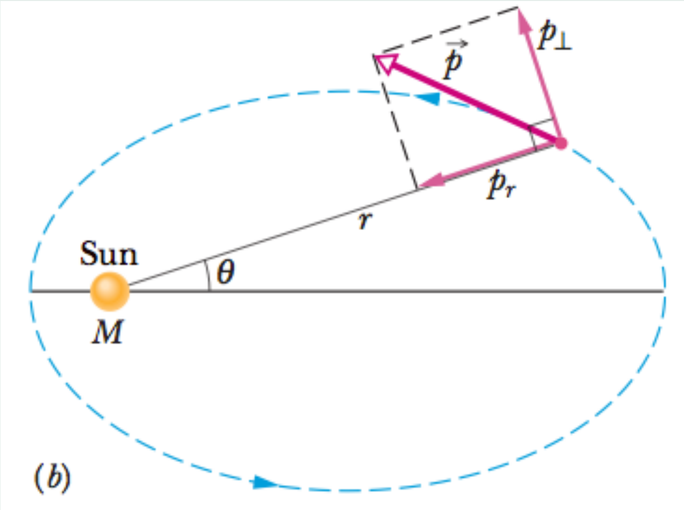
$$f = ae = d(C, F) = d(C, F')$$

$R_p =$ **perihelion**

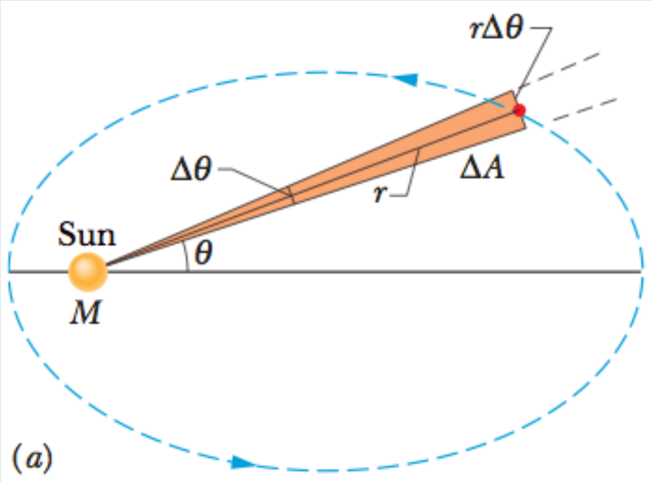
$R_a =$ **aphelion**

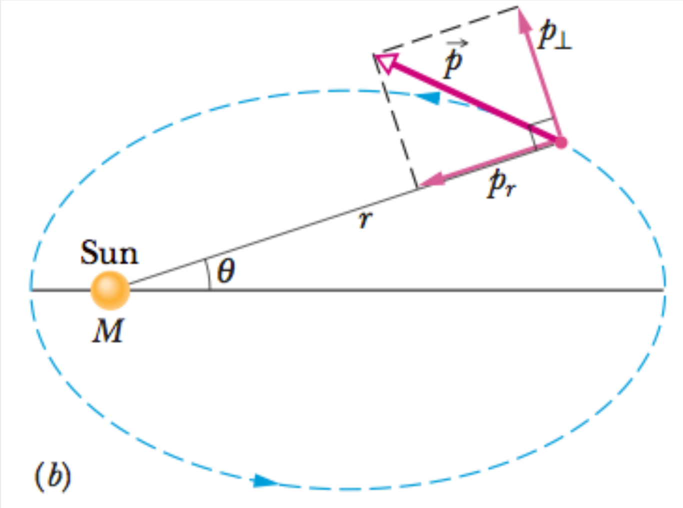
The Law of Areas





A line that connects a planet to the Sun sweeps out equal areas in the plane of the planet's orbit in equal time intervals; that is, the rate dA/dt at which it sweeps out area A is constant.





$$\frac{dA}{dt} = \frac{1}{2} r^2 \frac{d\theta}{dt}$$

Angular momentum:

$$L = r p_\perp = m r^2 \omega \qquad \frac{dA}{dt} = \frac{L}{2m}$$

Note: $\vec{L}$ is conserved since $\vec{\tau}_{F_g} = \vec{r} \times \vec{F}_g = 0$

The Law of Periods

The square of the period of any planet is proportional to the cube of the semimajor axis of its orbit.

For a circular orbit $(a = b = r)$ Netwon's 2nd law

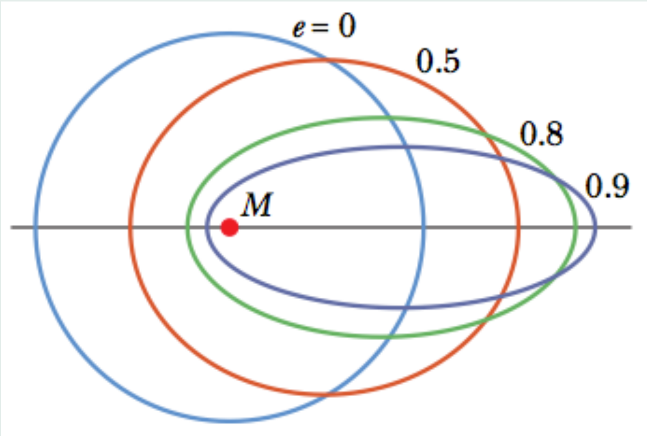
$$\vec{F}_g = m\vec{a}_c \;\Rightarrow\; \frac{GmM}{r^2} = m\omega^2 r$$

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{r^3}{GM}} \;\Rightarrow\; T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

For **any** elliptical orbit:

$$T^2 = \left(\frac{4\pi^2}{GM}\right) a^3$$

• Satellites: orbits and energy



- Potential energy:

$$U = -\frac{GMm}{r}$$

- **Circular** orbit:

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$\Downarrow$$

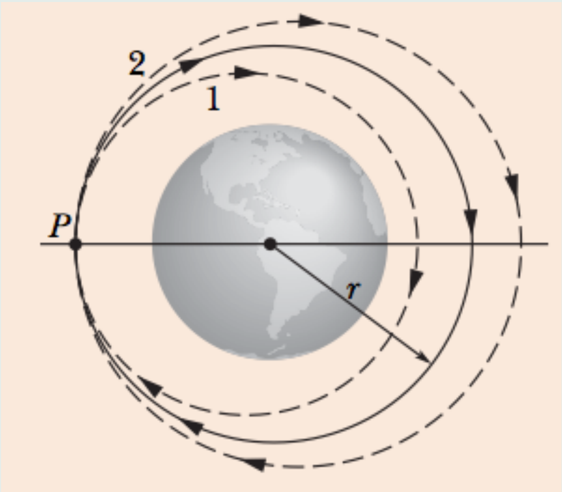
$$E = K + U = \frac{GMm}{2r} - \frac{GMm}{r}$$

$$E = -\frac{GMm}{2r}$$

- **Elliptical** orbit:

$$E = -\frac{GMm}{2a}$$

i-Clicker

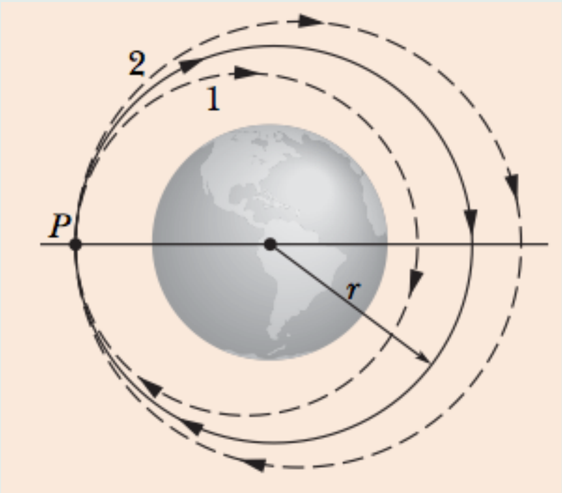


A space shuttle is initially in a circular orbit of radius r about Earth. At point P the pilot briefly fires a forward-pointing thruster to decrease the shuttles kinetic energy K and mechanical energy E. Which of the dashed elliptical orbits shown in the figure will the shuttle then take?

$A)$ inner orbit

$B)$ outer orbit

i-Clicker



$$E = -GMm/2a$$
$$E \searrow \Leftrightarrow a \searrow$$

A space shuttle is initially in a circular orbit of radius r about Earth. At point P the pilot briefly fires a forward-pointing thruster to decrease the shuttles kinetic energy K and mechanical energy E. Which of the dashed elliptical orbits shown in the figure will the shuttle then take?

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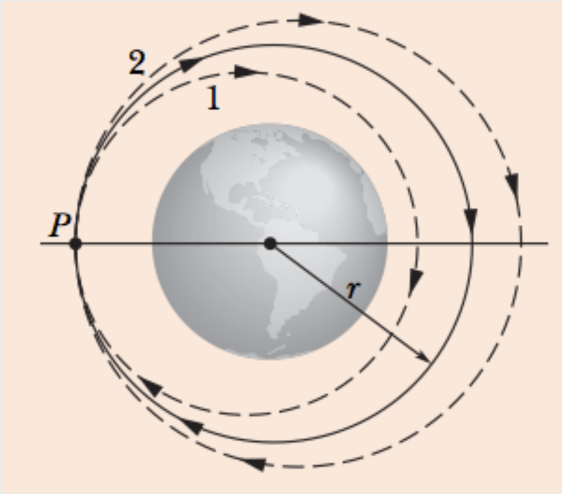

In the same situation, is the orbital period T of the shuttle (the time to return to P) then

A) greater than,

B) less than, or

C) the same as

in the circular orbit?

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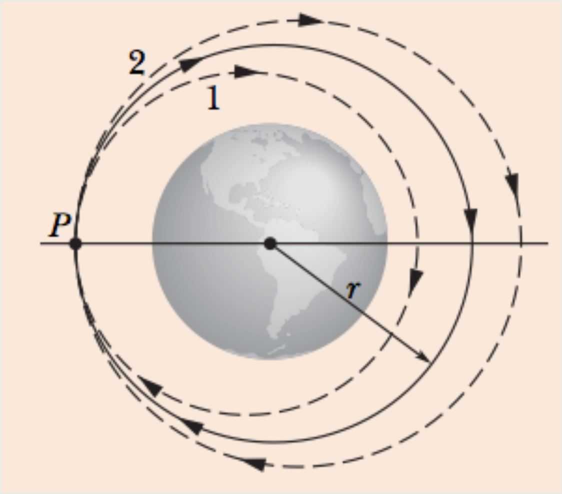


In the same situation, is the orbital period T of the shuttle (the time to return to P) then

$A)$ greater than,

$B)$ less than, or

$C)$ the same as

in the circular orbit?

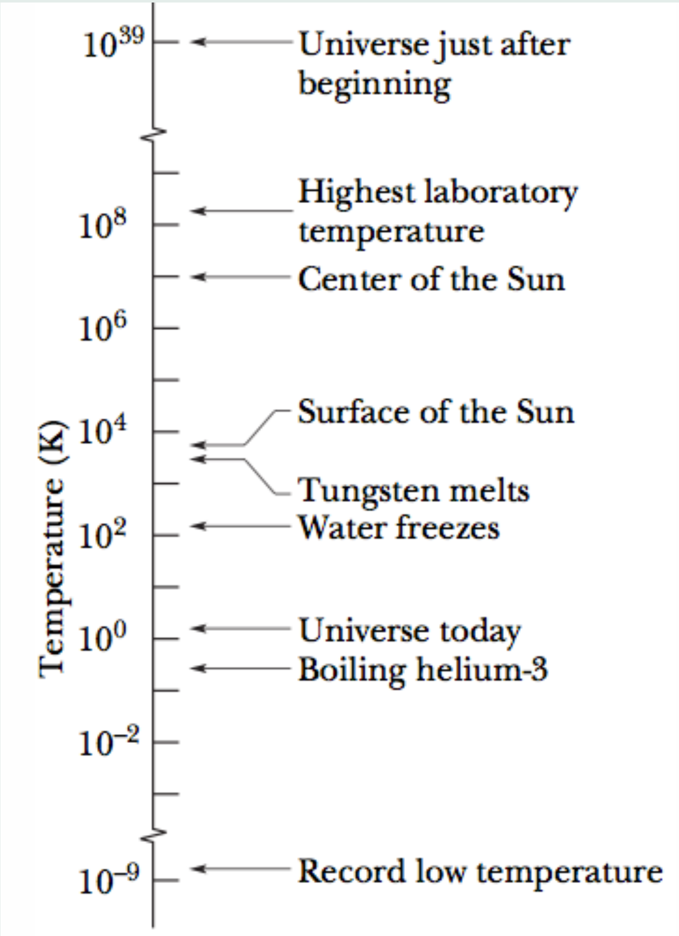
$$T^2 \sim a^3$$

18. Temperature, heat and the first law of thermodynamics

What is temperature?

Intrinsic macroscopic quantity which measures the kinetic energy of the **average** microscopic constituent (atom, molecule . . .) of a physical system.

- Temperature is one of the 7 SI base quantities.
- Unit: **Kelvin**
- $T \geq 0$
- $T = 0$ **absolute zero**



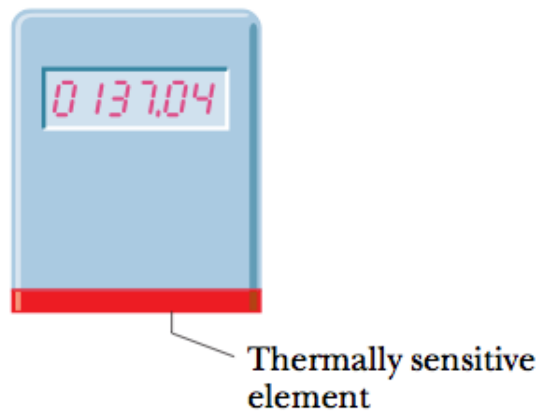


Fig. 18-2 A thermoscope. The numbers increase when the device is heated and decrease when it is cooled. The thermally sensitive element could be—among many possibilities—a coil of wire whose electrical resistance is measured and displayed.

Thermoscope:

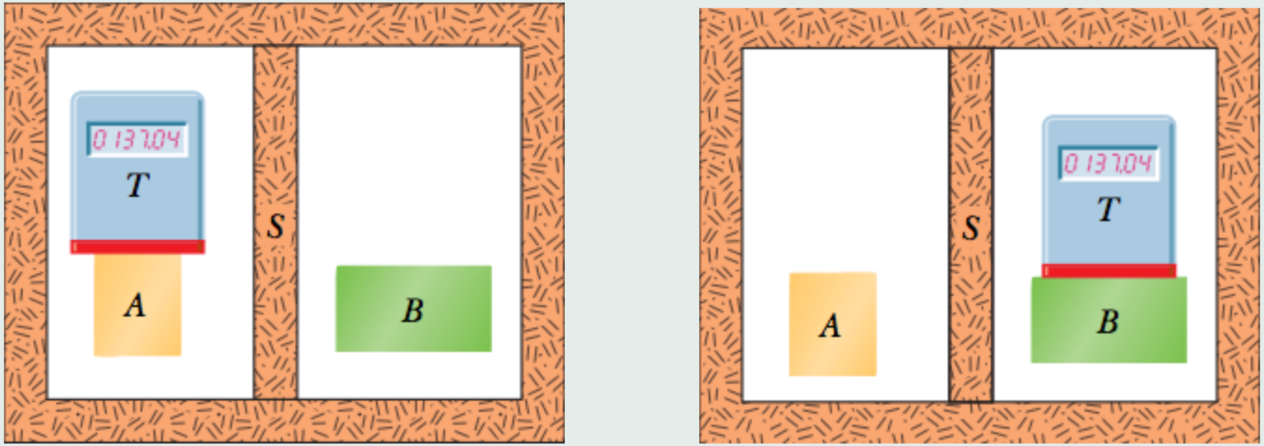
A physical instrument which is sensitive to **heat**.

Not a **thermometer** yet; not calibrated.

The Zeroth Law of Thermodynamics

If bodies A and B are each in thermal equilibrium with a third body T, then A and B are in thermal equilibrium with each other.

Thermal equilibrium: two bodies are in thermal equilibrium if no energy transfer occurs when the two bodies are in contact.



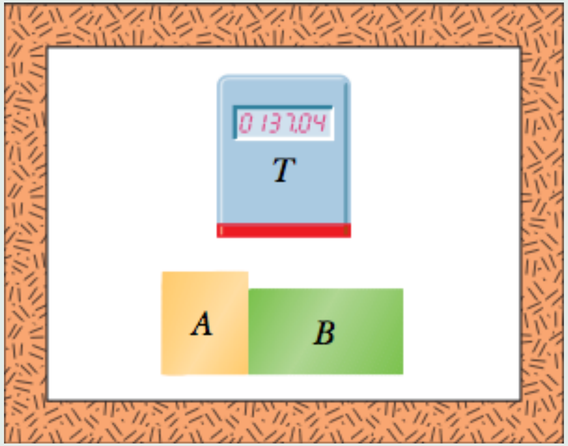


Fig. 18-3 (*a*) Body *T* (a thermoscope) and body *A* are in thermal equilibrium. (Body *S* is a thermally insulating screen.) (*b*) Body *T* and body *B* are also in thermal equilibrium, at the same reading of the thermoscope. (*c*) If (*a*) and (*b*) are true, the zeroth law of thermodynamics states that body *A* and body *B* are also in thermal equilibrium.

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- **Measuring temperature**

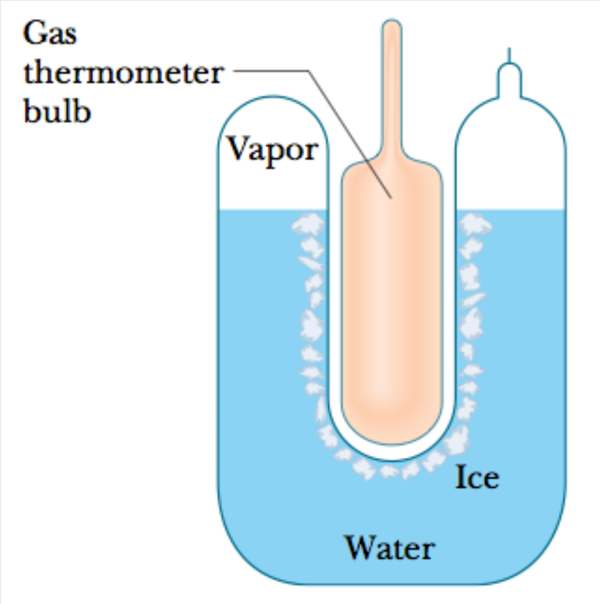

Fig. 18-4 A triple-point cell, in which solid ice, liquid water, and water vapor coexist in thermal equilibrium. By international agreement, the temperature of this mixture has been defined to be 273.16 K. The bulb of a constant-volume gas thermometer is shown inserted into the well of the cell.

Triple point of water: liquid water, vapors, and ice in thermal equilibrium.

International agreement: $T_3 = 273.16\,\mathrm{K}$.

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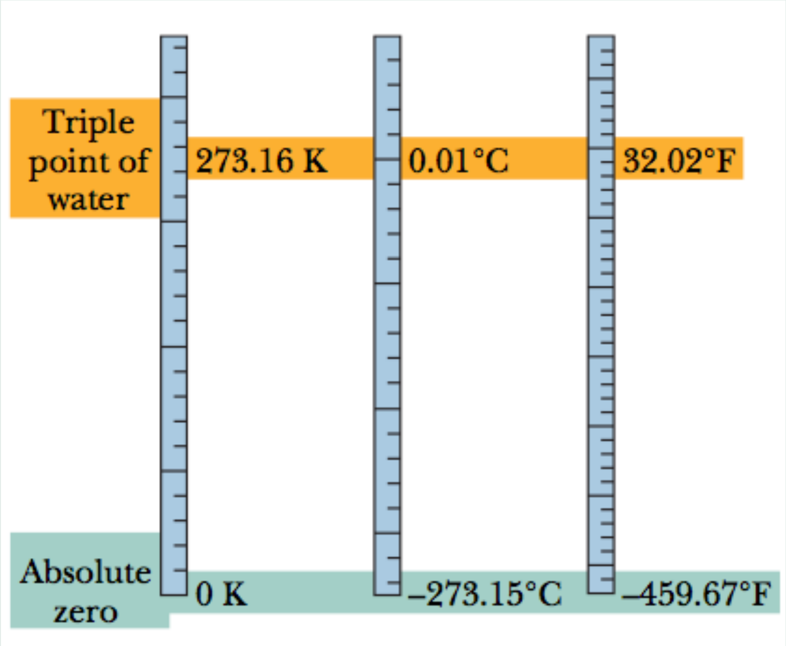
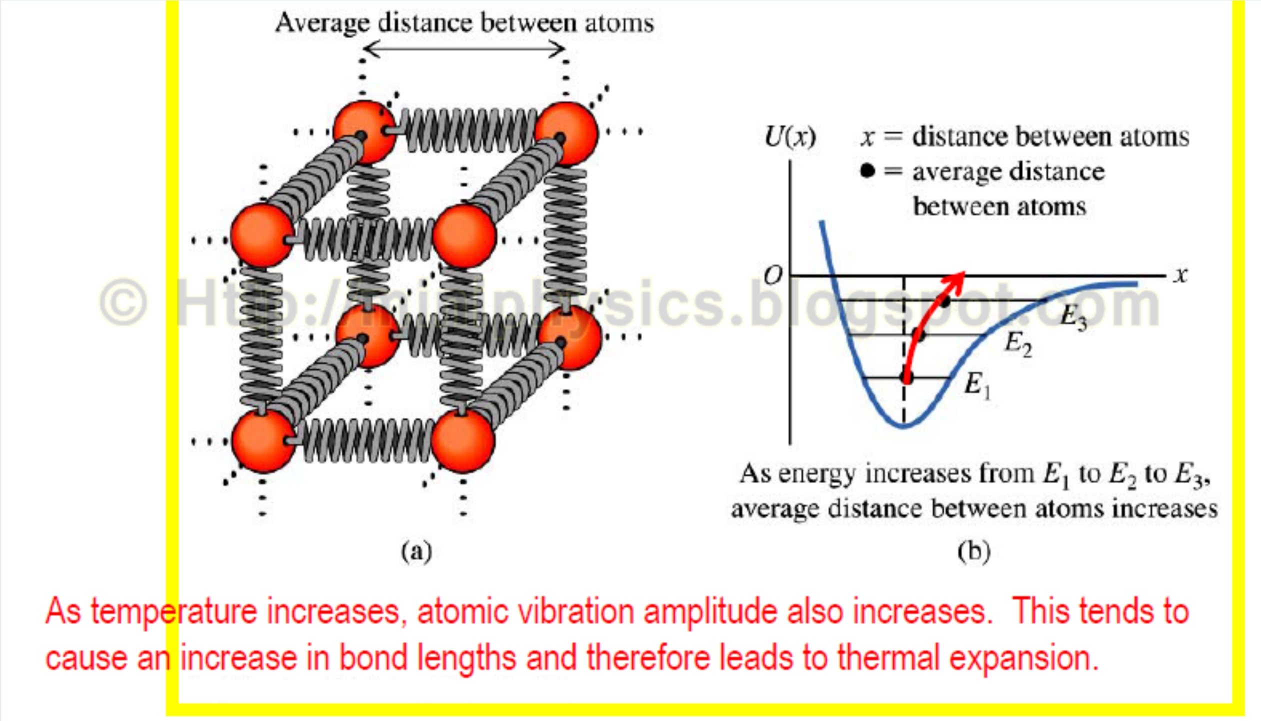
- **Celsius and Fahrenheit scales**



$$T_C = T - 273.15^\circ$$

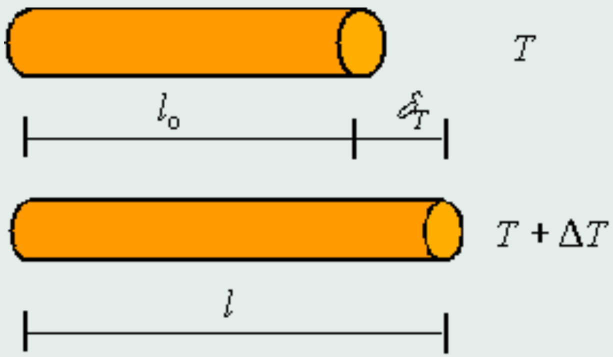
$$T_F = \frac{9}{5}T_C + 32^\circ$$

- **Thermal expansion**



$T \nearrow \Rightarrow$ atoms further appart $\Rightarrow$ object expands

Linear expansion



$$T \nearrow$$
$$\Downarrow$$
length of rod $\nearrow$

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

α = coefficient of linear expansion

Some Coefficients of Linear Expansion[a]

Substance	$\alpha\,(10^{-6}/C^\circ)$	Substance
Ice (at 0°C)	51	Steel
Lead	29	Glass (ordinary)
Aluminum	23	Glass (Pyrex)
Brass	19	Diamond
Copper	17	Invar[b]
Concrete	12	Fused quartz

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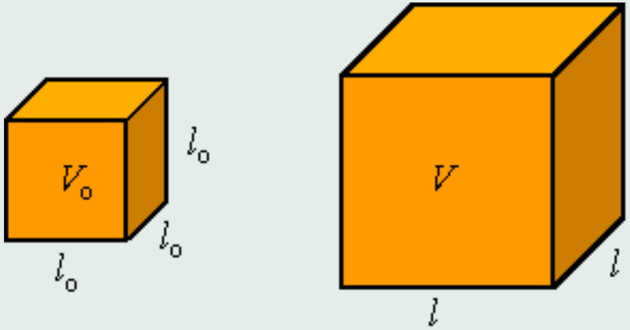
Volume expansion



$$T \nearrow$$
$$\Downarrow$$
volume of solid cube $\nearrow$

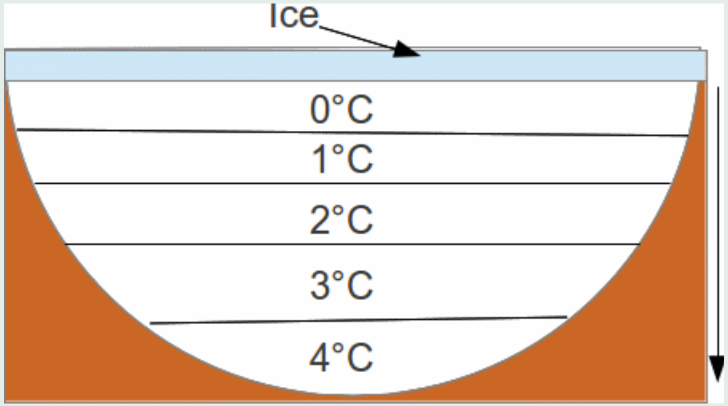
$$\Delta V = \beta V \Delta T$$

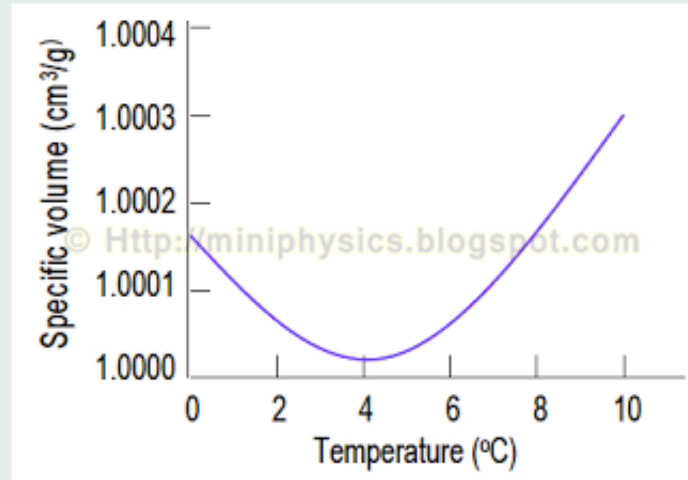
β = coefficient of volume expansion

$$\beta = 3\alpha$$

Note: same rule applies to liquids, with one important exception.

- **Anomalous expansion of water**

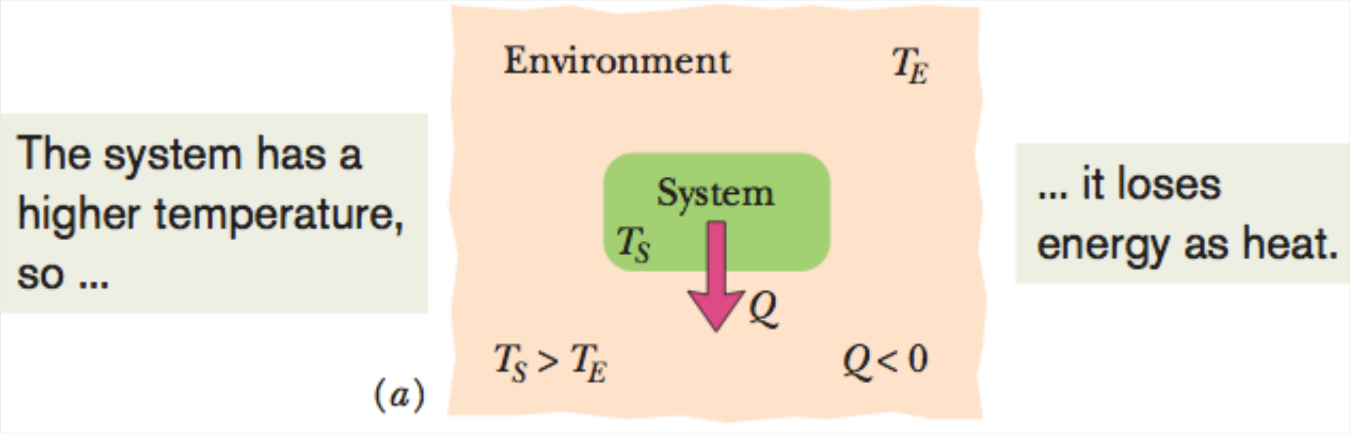




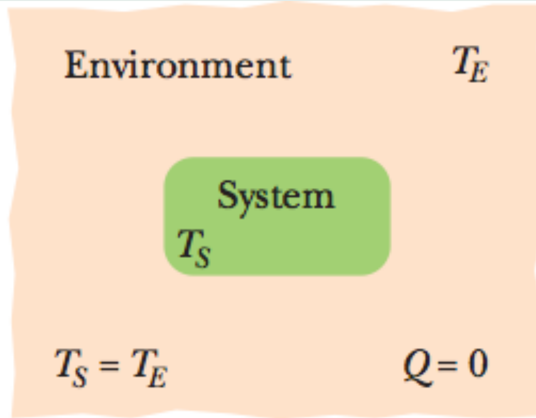
Water **contracts** from $0°C$ to $4°C$, hence ice is **lighter** than water at $1° \ldots 4°C$.

• Temperature and heat

Heat (Q): the **energy transferred** between a system and its environment because of a temperature difference that exists between them.



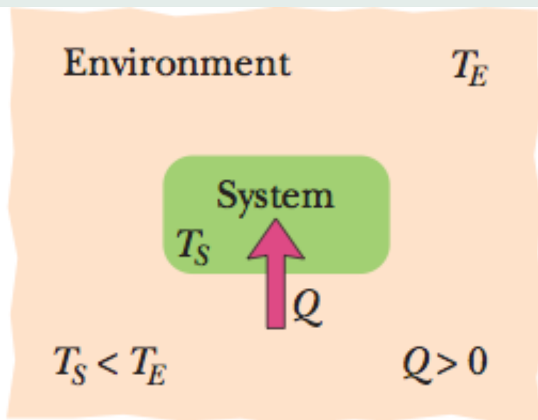
The system has the same temperature, so ...



(*b*)

... no energy is transferred as heat.

The system has a lower temperature, so ...



(*c*)

... it gains energy as heat.

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- **Heat Absorbtion by solids and liquids**

Heat capacity (C): the proportionality constant between the heat Q that the object absorbs or loses and the resulting temperature change ΔT of the object:

$$Q = C\Delta T$$

Specific heat (c): heat capacity per unit mass:

$$C = cm \;\Rightarrow\; Q = cm\Delta T$$

Units for C: J/K. Also **British thermal units (Btu)** and **Calories (cal)**

$$1\,\mathrm{cal} = 3.968\times10^{-3}\,\mathrm{Btu} = 4.1868\,\mathrm{J}$$

Phase change: transition from **solid** to **liquid** or form **liquid** to **vapors**.

Heat of transformation (L): the amount of energy per unit mass that must be transferred as heat when a sample completely undergoes a phase change.

$$Q = Lm$$

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Solid $\to$ liquid

Heat of fusion:

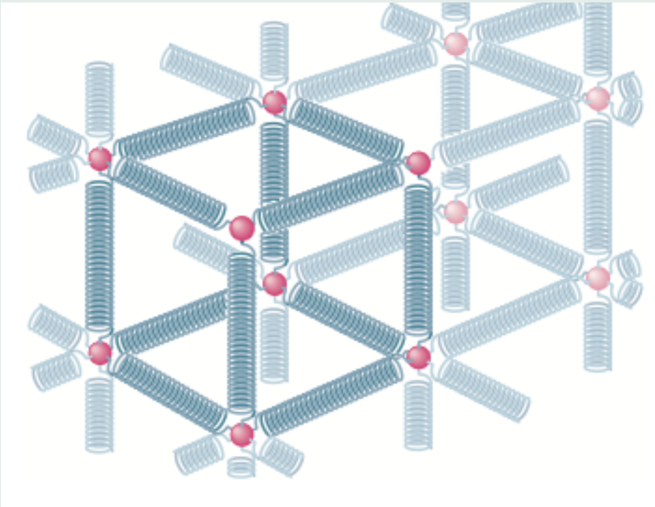
$$Q = L_F m$$

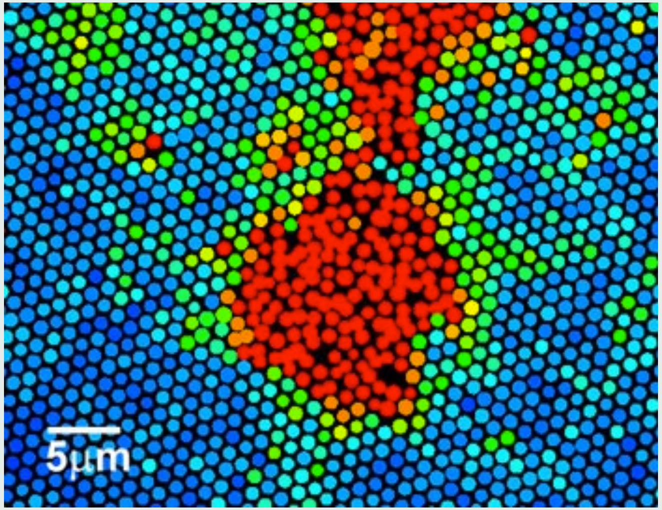
Liquid $\to$ vapors

Heat of vaporization:

$$Q = L_V m$$

Melting as an **order-disorder** transition





Increasing the kinetic energy of atoms eventually leads to a distruction of atomic bonds.

Example:

A copper slug of mass $m_c = 75\,\mathrm{g}$ is heated to a temperature $T = 312^\circ\,\mathrm{C}$. The slug is then dropped into a glass beaker containing $m_w = 220\,\mathrm{g}$ of water. The heat capacity C_b of the beaker is $45\,\mathrm{cal/K}$. The initial temperature T_i of the water and the beaker is $12^\circ\,\mathrm{C}$. Assuming that the slug, beaker, and water are an isolated system and the water does not vaporize, find the final temperature T_f of the system at thermal equilibrium.

Heated slug $\xrightarrow{\text{heat}}$ Water + beaker

- Heat absorbed by the water:

$$Q_w = m_w c_w (T_f - T_i) > 0$$

- Heat absorbed by the beaker:

$$Q_b = C_b (T_f - T_i) > 0$$

- Heat lost by the copper slug:

$$Q_c = m_c c_c (T_f - T) < 0$$

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- Isolated system:

$$Q_w + Q_b + Q_c = 0$$

$$m_w c_w (T_f - T_i) + C_b (T_f - T_i) + m_c c_c (T_f - T) = 0$$

$$T_f = \frac{m_w c_w T_i + C_b T_i + m_c c_c T}{m_w c_w + C_b + m_c c_c}$$