Good morning!

Lab 9 is in B9

Please, login into webassing, locate LectureMCQ_L22 (PY105) and answer question 1 (but ONLY Q1!).

Gravity

(examples)

How big is the gravitational force?

Between a large planet and a small object.

$G = 6.67 \times 10^{-11}$ Nm^2/kg^2

$M_{Earth} = 6 \times 10^{24}$ kg

$R_{Earth} = 6.4 \times 10^{6}$ m

$$|F_g| = \frac{GmM}{r^2}$$

Webassign: L22_Q2

Find the force acting from the Earth on a 1 kg object placed on its (the Earth's) surface.

0. ~ 1 N
1. ~ 10 N
2. ~ 20 N
3. ~ 30 N
4. ~ 40 N

… Etc.

$G = 6.67\text{x}10^{-11}\ \text{Nm}^2/\text{kg}^2$

$M_{Earth} = 6\text{x}10^{24}\ \text{kg}$

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[Webassign: L22_Q2](#)

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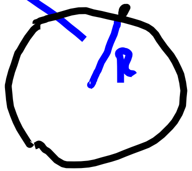


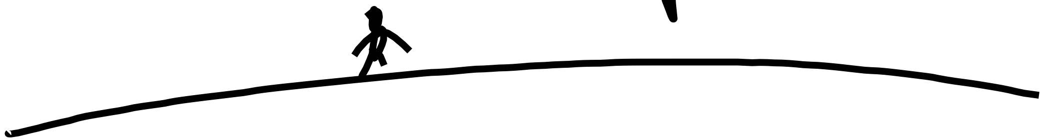
$|F| = ?$

Find the force acting from the Earth on a 1 kg object placed on its surface.

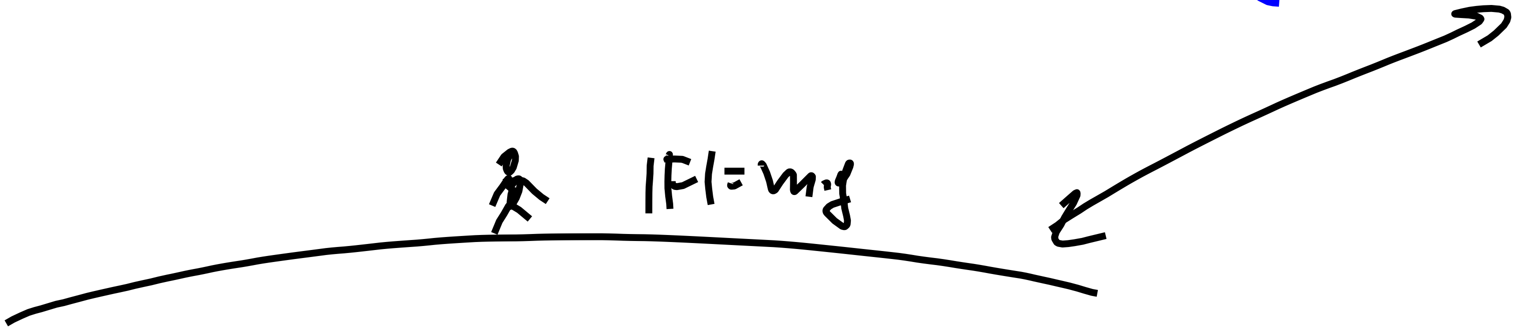
0. ~ 1 N
1. ~ 10 N
2. ~ 20 N
3. ~ 30 N
4. ~ 40 N

… Etc.

$F = m \cdot g = 1 \cdot 10 = 10N$



$$|F| = G\frac{mM}{r^2} = 6.67\cdot 10^{-11}\,\frac{1\cdot 6\cdot 10^{24}}{(64\cdot 10^{6})^2} = \ldots 10N$$



$$|F| = m\cdot g$$

$G = 6.67\text{x}10^{-11}\ \text{Nm}^2/\text{kg}^2$

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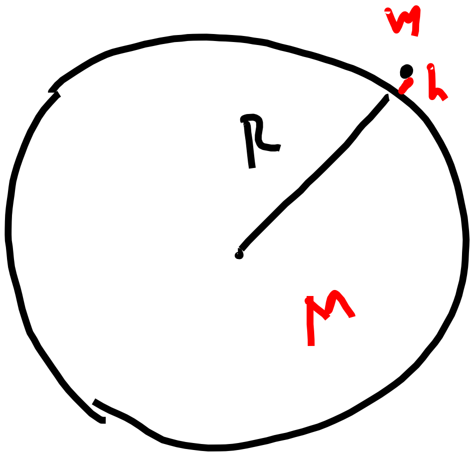

$F_{g} = m \cdot a$

$\downarrow$

$$G\frac{\cancel{m}\cdot M}{(R+h)^2} = \cancel{m}\cdot a$$

$$a = \frac{GM}{(R+h)^2}\ ;\ \text{if}\ \underline{\underline{h \to 0}} \Rightarrow g \approx \frac{GM}{R^2}$$

Calculating *g*

Newton's form of the equation for the force of gravity must be consistent with the *mg* we have been using up to this point in the course:

$$\frac{GmM}{r^2} = mg$$

For an object of mass *m* at the surface of the Earth, this tells us that:

$$g = \frac{GM_E}{R_E^2} = \frac{(6.67 \times 10^{-11}\ \mathrm{N\,m^2/kg^2}) \times (5.97 \times 10^{24}\ \mathrm{kg})}{(6.38 \times 10^{6}\ \mathrm{m})^2} = 9.8\ \mathrm{m/s^2}$$

The radius of the Earth is so large compared to the heights of objects around us that we find that *g* does not vary significantly in our common experience.

Calculating *g*

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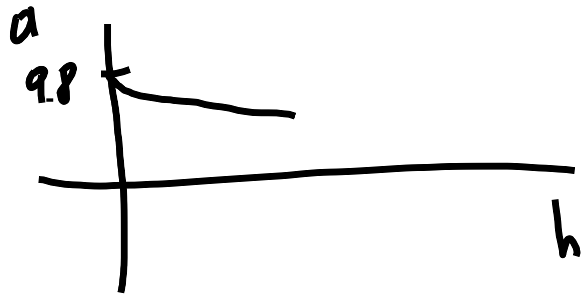
The radius of the Earth is so large compared to the heights of objects around us that we find that *g* does not vary significantly in our common experience.

Calculate the Earth's gravitational acceleration 20 km above the surface.

$$a = G \frac{M}{(R+h)^2} =$$

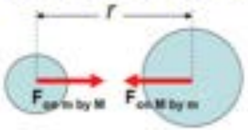
$$= 6.67 \cdot 10^{-11} \frac{6 \cdot 10^{24}}{(6.4 \cdot 10^6 + 20000)^2} =$$

$$= 9.7$$



Newton's Law of Universal Gravitation

Two objects of mass m and M, with their centers of mass separated by a distance r, exert attractive forces on one another.
(Equal magnitude but opposite direction, by Newton's Third Law)

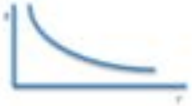


The magnitude of this gravitational force is given by:

$$F_g = \frac{GmM}{r^2}$$

where G is the universal gravitational constant:

$$G = 6.67 \times 10^{-11}\ \text{N m}^2/\text{kg}^2$$



Calculate the *net* gravitational force acting on a 1 T satellite located exactly at the middle point on the line connecting the Moon and the Earth.

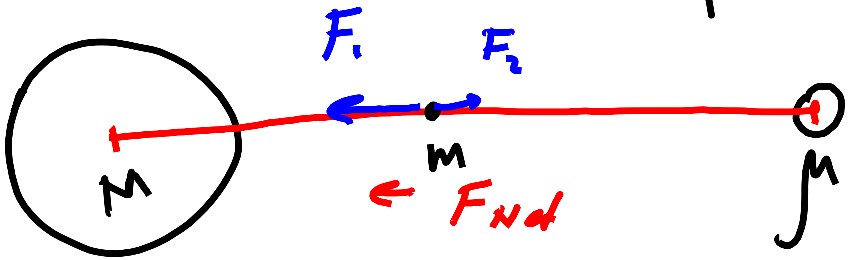
$M_{Earth} = 6 \times 10^{24}$ kg

$M_{Moon} = 7 \times 10^{22}$ kg

$D_{Moon\text{-}Earth} = 385000$ km

$$|F_{Net}| = F_1 - F_2 =$$

$$= G \frac{mM}{\left(\frac{1}{2}D\right)^2} - G \frac{m\mathcal{M}}{\left(\frac{1}{2}D\right)^2}$$



1 T = 1000 kg

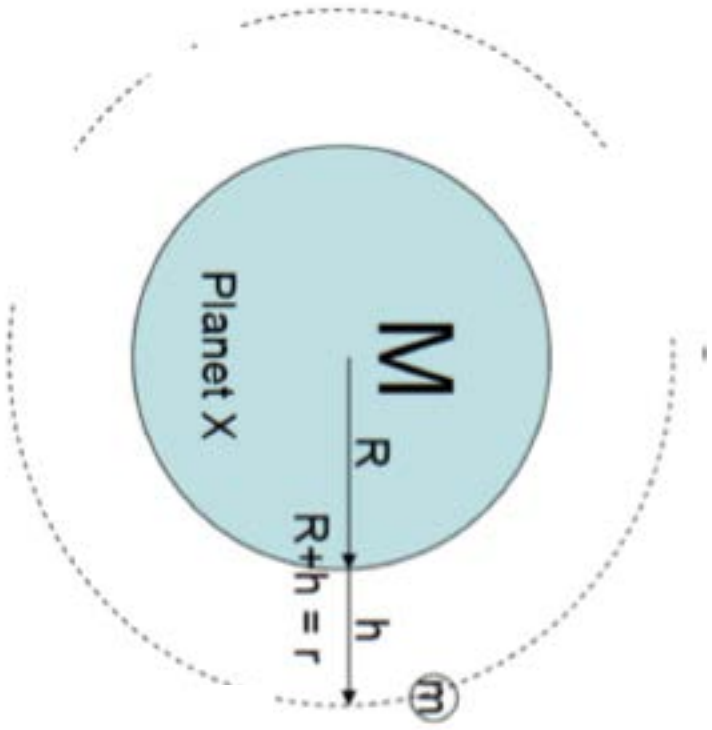
Circular Orbits

- Orbit radius r = Planet radius R + height h above

Webassign: L22_Q3

For a small satellite orbiting a large planet with a constant speed, the acceleration at the shown instant points:

1. Up
2. Down
3. Left
4. Right
5. Away from the planet



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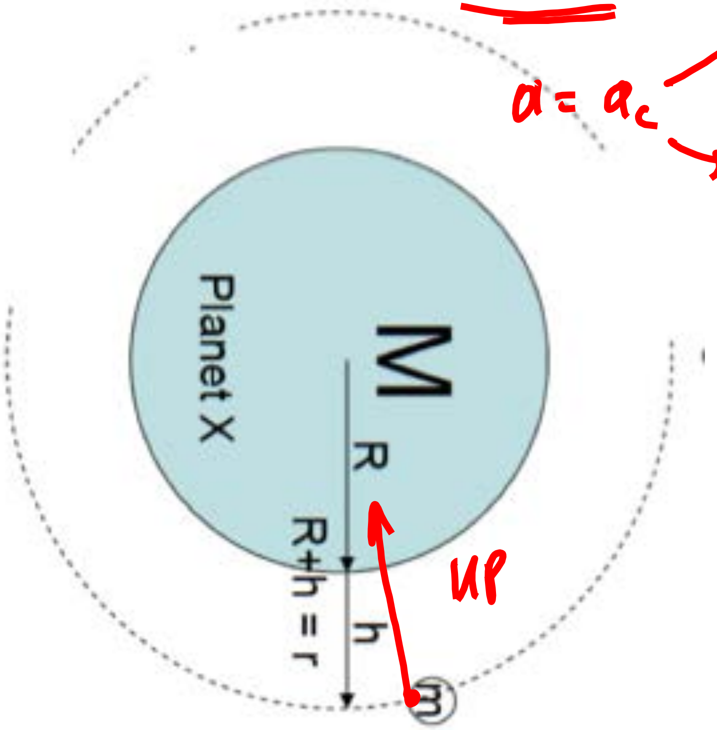
UCM

$a = a_c$ → 1) ↑ → 2) $\frac{v^2}{R}$



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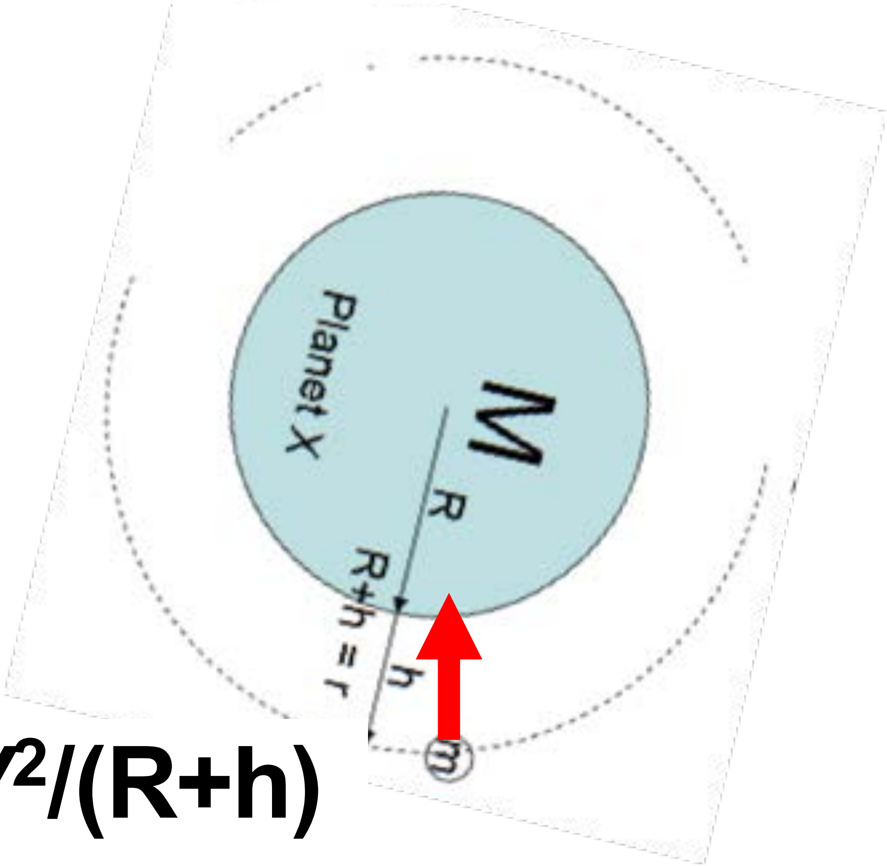

$$a = a_C = V^2/(R+h)$$

Circular Orbits

Orbit radius r = Planet radius R + height h above

$G = 6.67\text{x}10^{-11}\ \text{Nm}^2/\text{kg}^2$

$M_{\text{Earth}} = 6\text{x}10^{24}$ kg

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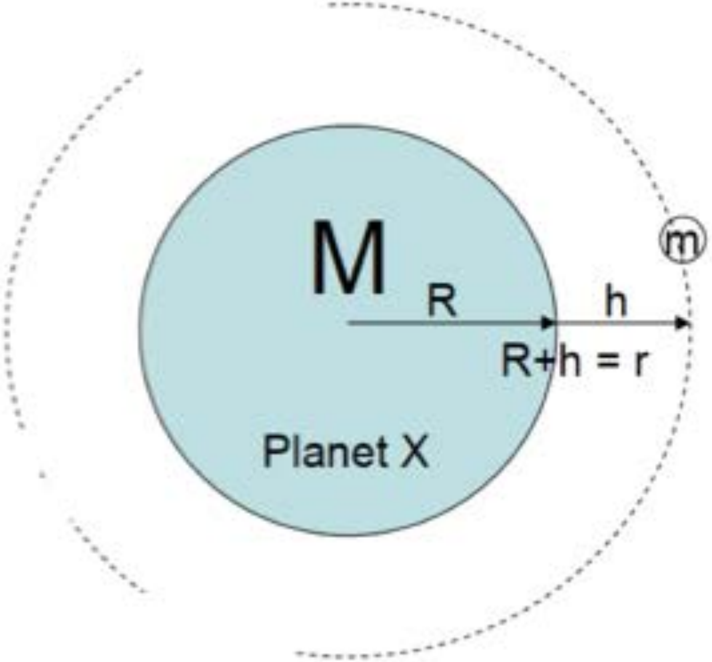

For a 1 T satellite orbiting the Earth 20 km about the surface, calculate … everything.

Circular Orbits

$G = 6.67 \times 10^{-11}\ Nm^2/kg^2$

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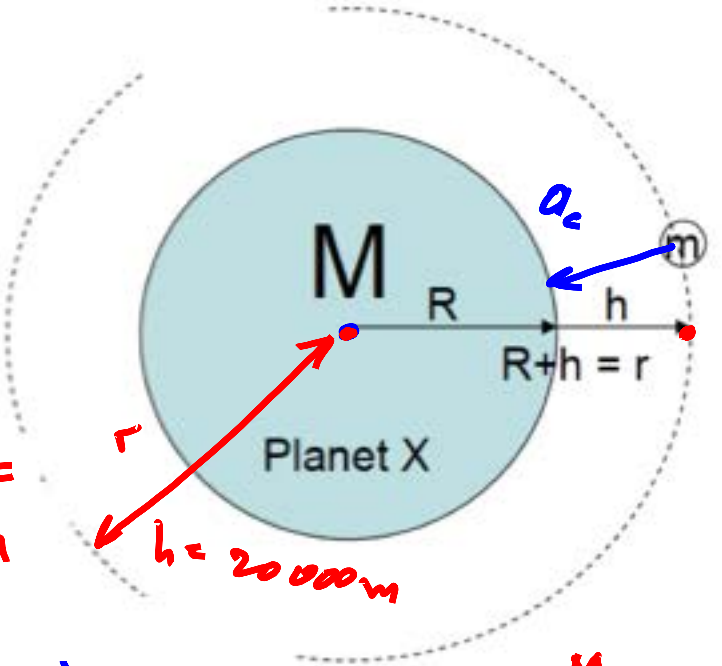
Orbit radius r = Planet radius R + height h above



For a 1 T satellite orbiting the Earth 20 km about the surface, calculate … everything.

$a_c \rightarrow F_{net} \rightarrow F_g$

$\downarrow m$

$$\underbrace{G\frac{\cancel{m}M}{r^{\cancel{2}}}} = \cancel{m}\cdot a = \underbrace{\frac{v^2}{\cancel{r}}}$$

$$G\frac{M}{r} = v^2$$

$$KE = \frac{mv^2}{2} \rightarrow KE = \frac{m}{2}\cdot G\frac{M}{r} = \frac{1}{2}\cdot \underbrace{G\frac{mM}{r}}$$

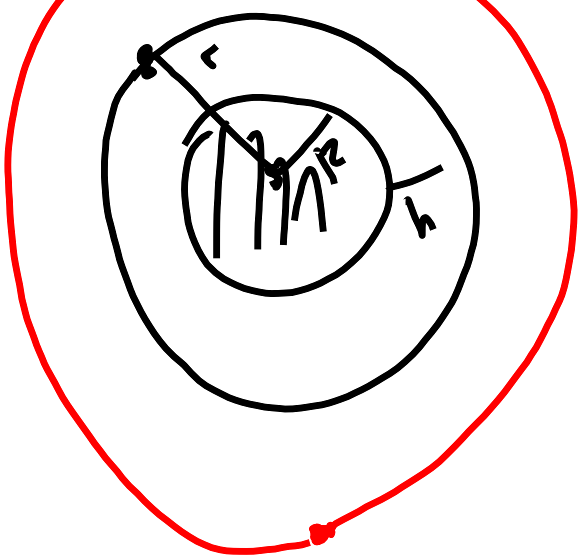
$$v = \sqrt{G\frac{M}{r}}$$

$$KE = \frac{1}{2}\cdot(-U)$$

$$\underbrace{U = -G\frac{mM}{r}}$$

$$ME = KE + U = -\frac{U}{2} + U = \frac{U}{2}$$

$$V = \sqrt{G\frac{M}{r}}$$



$$r = R + h$$

in $1\,T \Rightarrow L = 2\pi r$

$$V = \frac{L}{T} = \frac{2\pi r}{T}; \qquad T = \frac{2\pi r}{V}$$

$$T = \frac{2\pi r}{\sqrt{G\frac{M}{r}}} = \frac{2\pi r\sqrt{r}}{\sqrt{GM}};$$

$$T^2 = \frac{4\pi^2 r^2 \cdot r}{GM} = \frac{4\pi^2}{GM} \cdot r^3$$

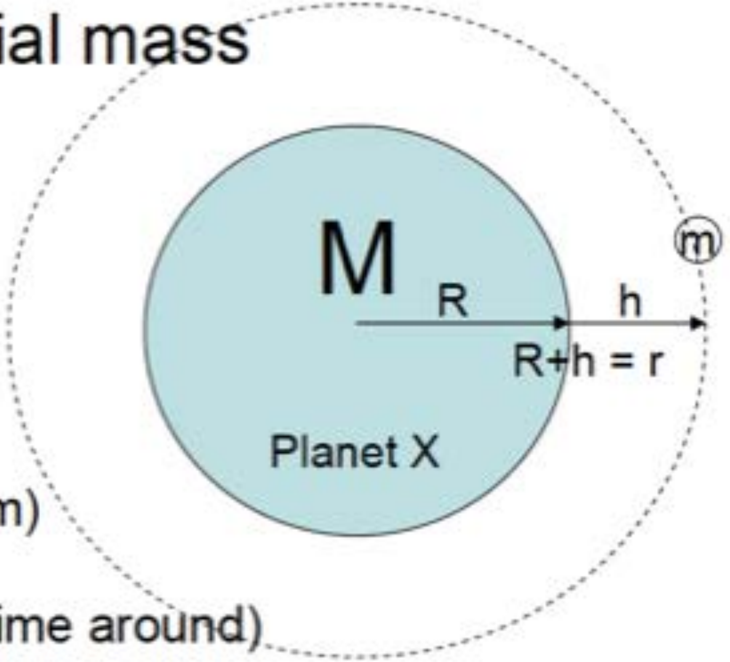
$$\hat{T}^2 = \frac{4\pi^2}{G\cdot M} \cdot \hat{r}^3$$

$$\Rightarrow \frac{T^2}{\hat{T}^2} = \frac{r^3}{\hat{r}^3}$$

Circular Orbits

- Orbit radius r = Planet radius R + height h above
- Gravitational mass = inertial mass
- $\mathbf{F} = m\mathbf{a}$

$$\frac{GM\cancel{m}}{r^2} = \frac{\cancel{m}\, v^2}{r}$$



(1) $GM = v^2 r$ (independent of m)

(2) $v = 2\pi r/T$ (circumference)/(time around)

(3) $GM = 4\pi^2 r^3 / T^2$ [substitute (2) in (1)]

or $T^2 = (4\pi^2/GM)\, r^3$ (Kepler's 3rd Law)

First Cosmic (orbital) Speed

Circular Orbits

- Orbit radius r = Planet radius R + height h above
- Gravitational mass = inertial mass
- **F** = m**a**

$$\frac{GM\cancel{m}}{r^2} = \frac{\cancel{m}\, v^2}{r}$$

(1) $GM = v^2 r$ (independent of m)

(2) $v = 2\pi r/T$ (circumference)/(time around)

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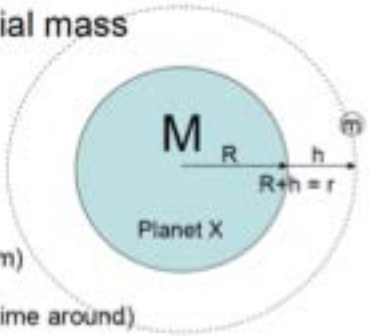


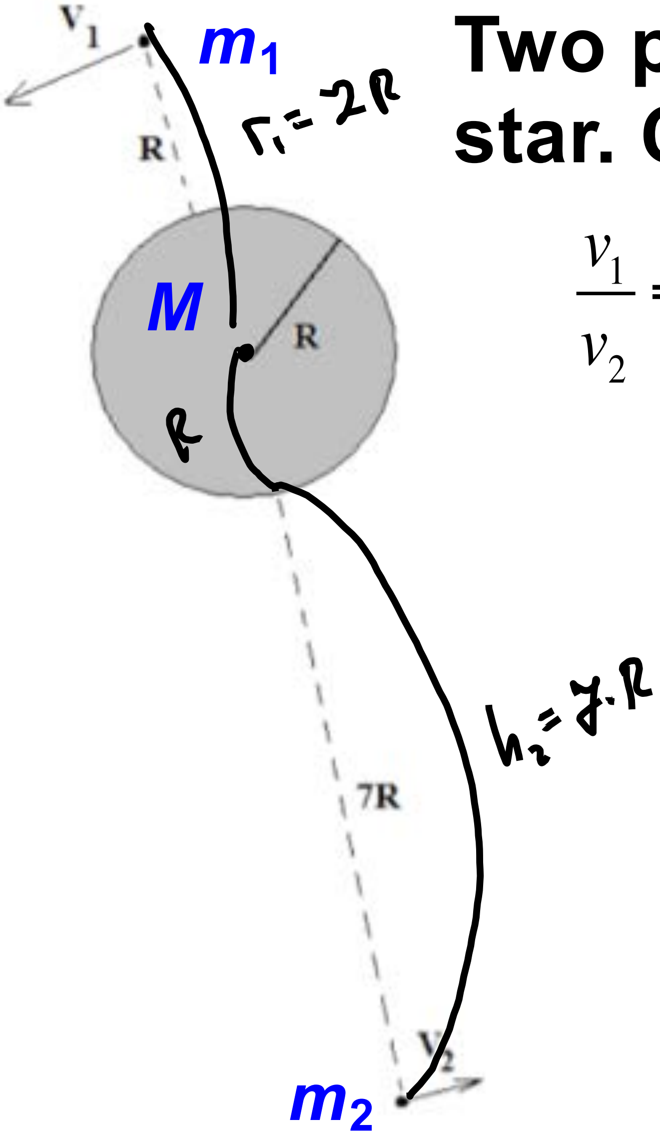
Calculate the speed and the period for a satellite orbiting the Earth *very close* to it.

≈

$G = 6.67\times10^{-11}\ Nm^2/kg^2$
$M_{Earth} = 6\times10^{24}$ kg
$R_{Earth} = 6.4\times10^{6}$ m

"very close" => h << R => set h = 0

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{GM}{R}} \approx 8\ km/s$$



Two planets orbit a star. Calculate …

$m_1 = 4m_2$

$$\frac{v_1}{v_2} = ?$$

$$V_1 = \sqrt{\frac{GM}{r_1}}; \quad V_2 = \sqrt{\frac{GM}{r_2}}$$

$$\frac{V_1}{V_2} = \frac{\sqrt{\frac{GM}{r_1}}}{\sqrt{\frac{GM}{r_2}}} = \sqrt{\frac{r_2}{r_1}} = \sqrt{\frac{8R}{2R}} = 2$$

$$\underline{V_1 = 2 \cdot V_2}$$

$$\frac{T_1}{T_2}; \quad \frac{KE_1}{KE_2}; \quad \frac{U_1}{U_2}; \quad \frac{ME_1}{ME_2}; \quad \frac{a_{c1}}{a_{c2}}; \quad \frac{F_1}{F_2}$$

Gravitational potential energy

$$W_{gravity} = U_i - U_f$$

The SAME connection!

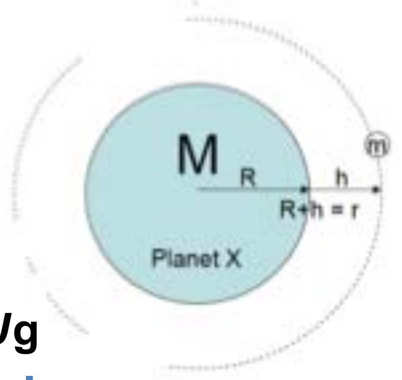
The energy of interaction (that is, the gravitational potential energy) of two objects of mass m and M separated by a distance r is:

The EXACT expression for GPE

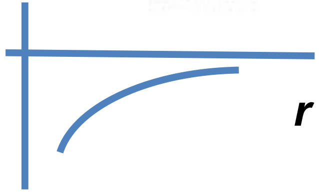
$$\boxed{U_g = -\frac{GmM}{r}}$$

or

$$U_G = -G\frac{m_1 m_2}{r}$$



The negative sign just tells us that the interaction is attractive.



Note that with this equation the potential energy is defined to be zero when r = infinity. This expression is derived using calculus.

(If you are curios: prove that close to the ground level U = mgh + const)

when h << R !

Escape speed

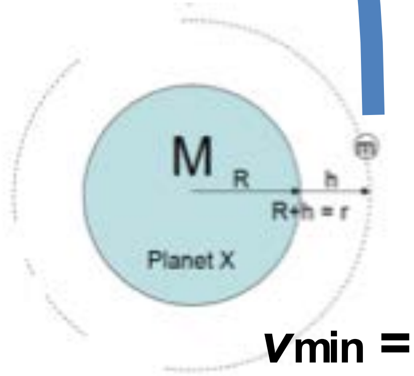
$r = \infty$
$v = 0$

How fast would you have to throw an object so it never came back down? Ignore air resistance. Let's find the escape speed - the minimum speed required to escape from a planet's gravitational pull.

How should we try to figure this out?

Attack the problem from a force perspective?

From an energy perspective?



v_{min} = ?

Set $h = 0$

Escape speed

How fast would you have to throw an object so it never came back down? Ignore air resistance. Let's find the escape speed - the minimum speed required to escape from a planet's gravitational pull.

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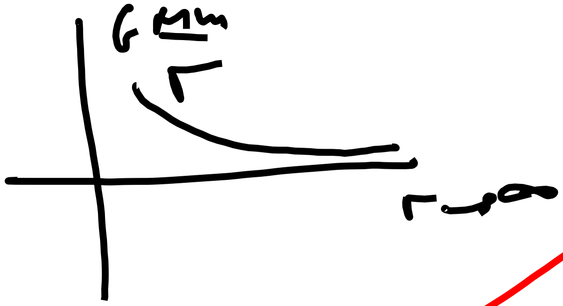
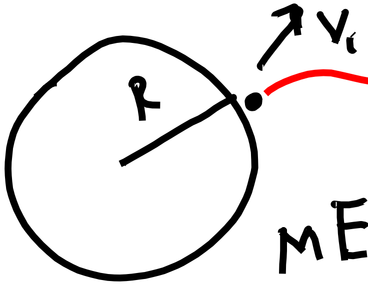




$r = \infty$

$v_f = 0$

$$ME_f = \frac{mv_f^2}{2} + U_f =$$

$$= 0 + 0$$

$$ME_i = \frac{mv_i^2}{2} + U_i = \frac{mv_i^2}{2} + -G\frac{mM}{r}$$

$$ME_i = ME_f \Rightarrow \frac{\cancel{m}v_i^2}{2} - G\frac{\cancel{m}M}{r} = 0$$

Escape speed (Second Cosmic Speed)

$$U_i + K_i = 0$$

If the total mechanical energy is negative, the object comes back. If it is positive, it never comes back.

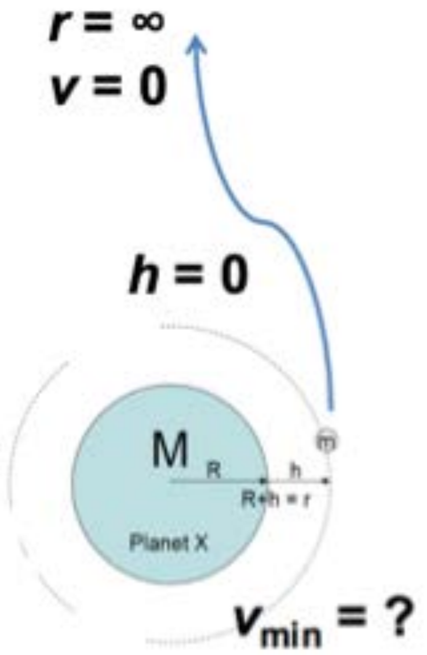
$$-\frac{GmM}{R} + \frac{1}{2}mv_{escape}^2 = 0$$

The mass of the object, *m*, does not matter. Solving for the escape speed gives:

$$v_{escape} = \sqrt{\frac{2GM}{R}}$$

M is the mass of the planet; *R* is the planet's radius.

For the Earth, we get v_{escape} = 11.2 km/s.



Gravity

DONE!

Next topics (do not read this slide)

Temperature, temperature scales, thermal contact, thermal conduction, thermal equilibrium, measuring temperature, heat, internal energy, meaning of temperature, meaning of heat, thermal expansion, coefficient of thermal expansion (CTE), linear, areal, and volumetric CTE, heat capacity, specific heat (capacity), thermally insulated system, heat balance equation (an equation for thermal equilibrium), phase transition, critical temperature, latent heat (capacity), method for solving thermal equilibrium problems, convection, thermal radiation, thermal conduction, thermal conductivity, the ideal gas, absolute temperature, a mole, the Avogadro's number, the universal gas constant, RMS values, the ideal gas law, iso – laws, graphs for gas processes (PV, VT, PT diagrams), the Boltzmann's constant, the meaning of the absolute temperature, the meaning of the pressure, degree of freedom, the equipartition theorem, monatomic, diatomic, polyatomic gas, calculating internal energy, the first law of thermodynamics, work done by gas, calculating specific heat (Cv, Cp), isothermal process, adiabatic process, thermodynamic cycle, work done over a cycle, heat engine, entropy, second law of thermodynamics, heat engine efficiency, the Carnot cycle, maximum (ideal) heat engine efficiency, a heat pump and a refrigerator(***the last topic of test 3***)

Temperature scales

A change by 1^{o} C is the same as a change by 1 K. The Celsius and Kelvin scales are just offset by about 273.

$$T \sim t + 273$$

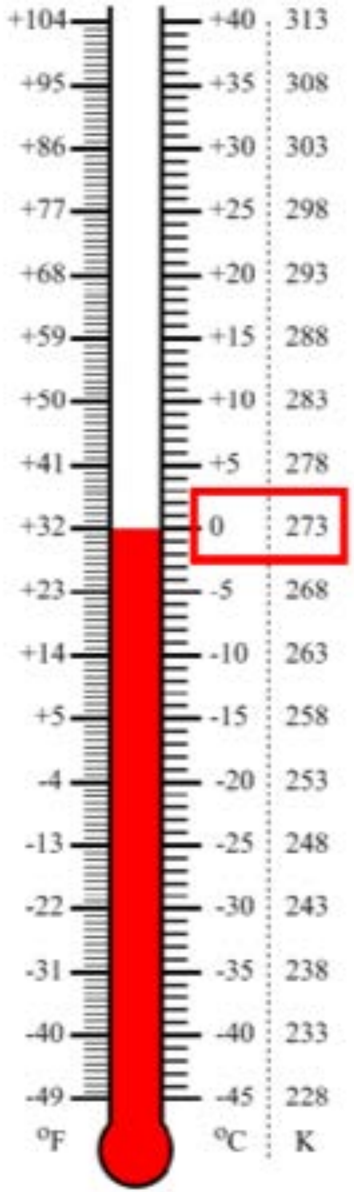
A change by 1^{o} C is the same as a change by 1.8^{o} F. To convert between Celsius and Fahrenheit we use:

$$T_C = \left(\frac{5°C}{9°F}\right)(T_F - 32°F)$$

$$T_F = \left(\frac{9°F}{5°C}\right)(T_C) + 32°F$$

Fahrenheit is relevant for weather reports, not this course

$$\boxed{\Delta T_F \neq \Delta T_C}$$



Equations involving temperature

If the equation involves T, use an absolute temperature (we generally use a <u>Kelvin temperature</u>).

If the equation involves ΔT, we can use Celsius or Kelvin.

$$\underline{T} = t + 273.15 \sim \underline{t + 273}$$

(never negative!)

$$\boxed{\Delta T = \Delta t} = \underline{K = C}$$

Thermal expansion

Linear expansion

Most materials expand when heated. As long as the temperature change isn't too large, each dimension of an object experiences a change in length that is proportional to the change in temperature.

$$\Delta T = \Delta t$$

$$\Delta L = L_0 \alpha \Delta t \qquad \text{or, equivalently,} \qquad L = L_0 (1 + \alpha \Delta T)$$

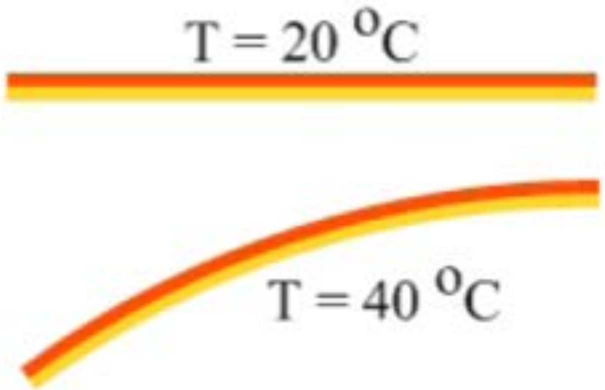
where L_0 is the original length, and α is the coefficient of linear expansion, which depends on the material.

Material	α (× 10^{-6}/°C)	Material	α (× 10^{-6}/°C)
Aluminum	23	Glass	8.5
Copper	17	Iron	12

Bimetallic strip

A bimetallic strip is made from two different metals that are bonded together. The strip is straight at room temperature, but it curves when it is heated. How does it work?

The metals have equal lengths at room temperature but different expansion coefficients, so they have different lengths when heated.



What is a common application of a bimetallic strip?

A bimetallic strip can be used as a switch in a thermostat. When the room is too cool the strip completes a circuit, turning on the furnace. The furnace goes off when the room (and the strip) warms up.

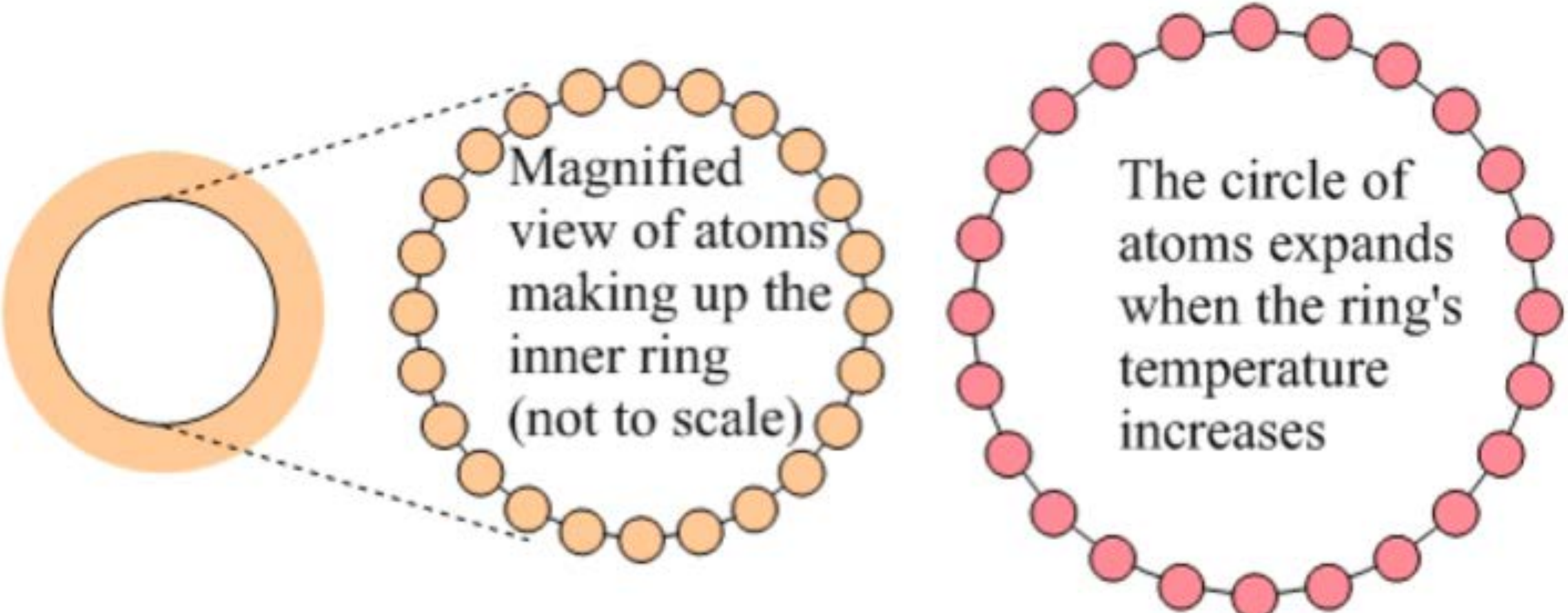
What happens to holes?

When an object is heated and expands, what happens to any holes in the object when we heat it up?

Webassign: L22 Q4

1. The holes get smaller
2. The holes stay the same size
3. The holes get larger

Holes expand, too



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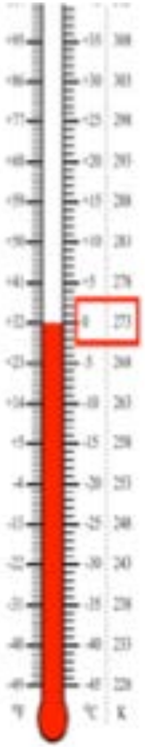
Volume expansion

For small temperature changes, we can find the new volume using:

$$\Delta V = V_0(3\alpha)\Delta T \quad \text{or, equivalently,} \quad V = V_0\left(1+\overbrace{3\alpha}^{\beta}\Delta T\right)$$

where V_0 is the original volume.

$\beta = 3 \cdot \alpha$



Why? $(1 + \alpha\Delta T)^3 = 1 + 3\alpha\Delta T + \cancel{3\alpha^2(\Delta T)^2} + \cancel{\alpha^3(\Delta T)^3}$

small | Really small | Really, really small

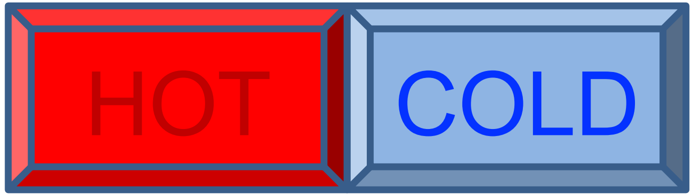
From Prof. Skocpol

HEAT

1 calorie = 4.184 J

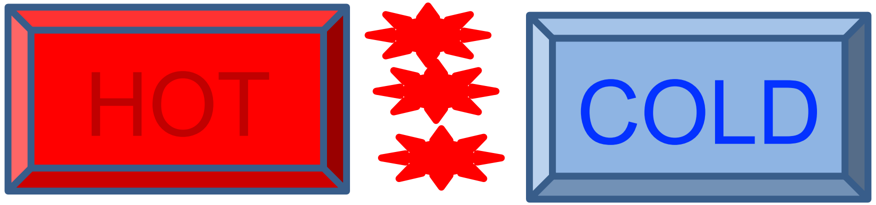
HEAT, *Q*, is the amount of *energy* one object can transfer to another object (or take from another object) to (a) change the temperature of another object without doing any work on it, or (b) change the phase of the object without doing any work on it.

Direct contact



OR

Radiation



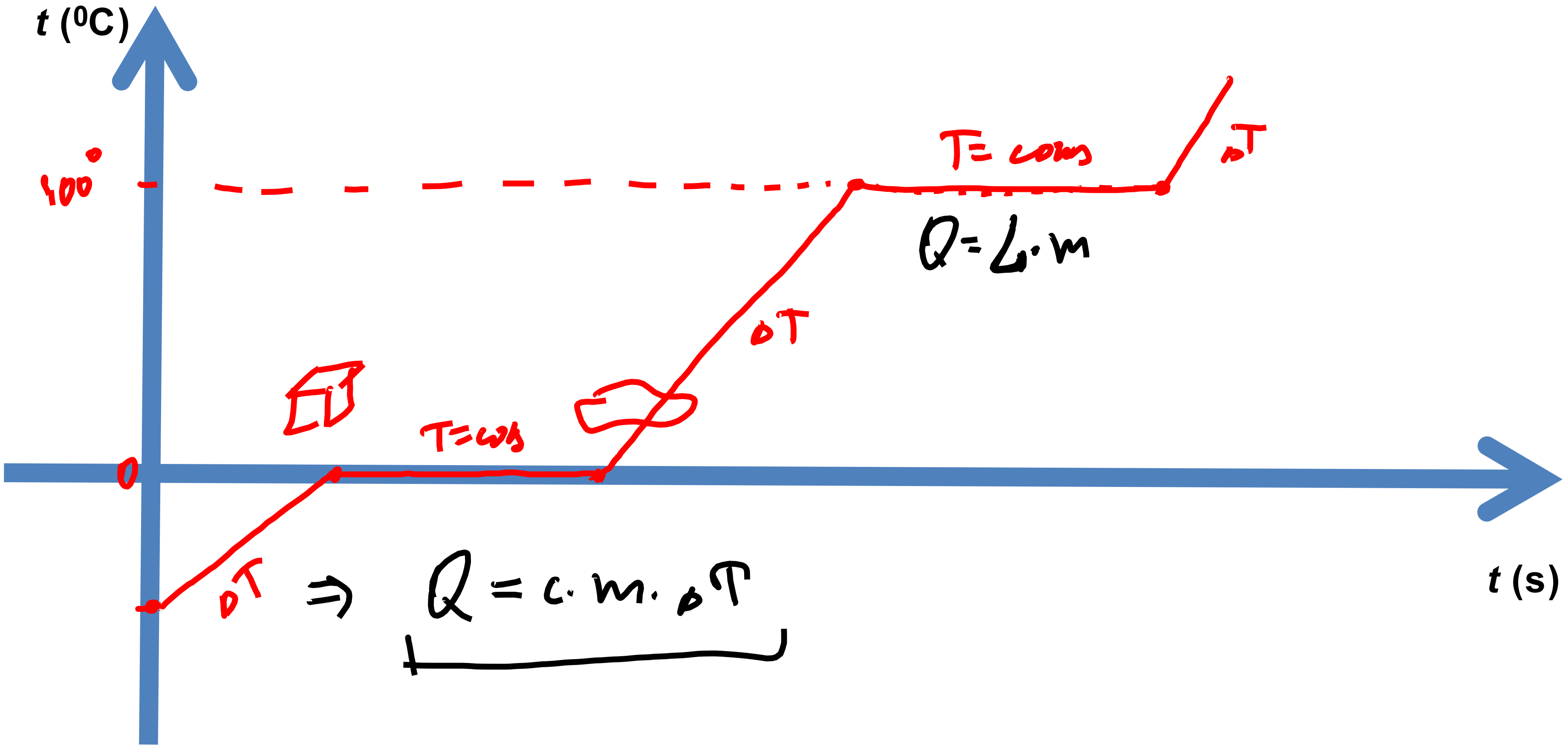
"When an ice cube is taken out of a freezer and placed on a heat plate it ***immediately*** starts melting"

Webassign: L22 Q5

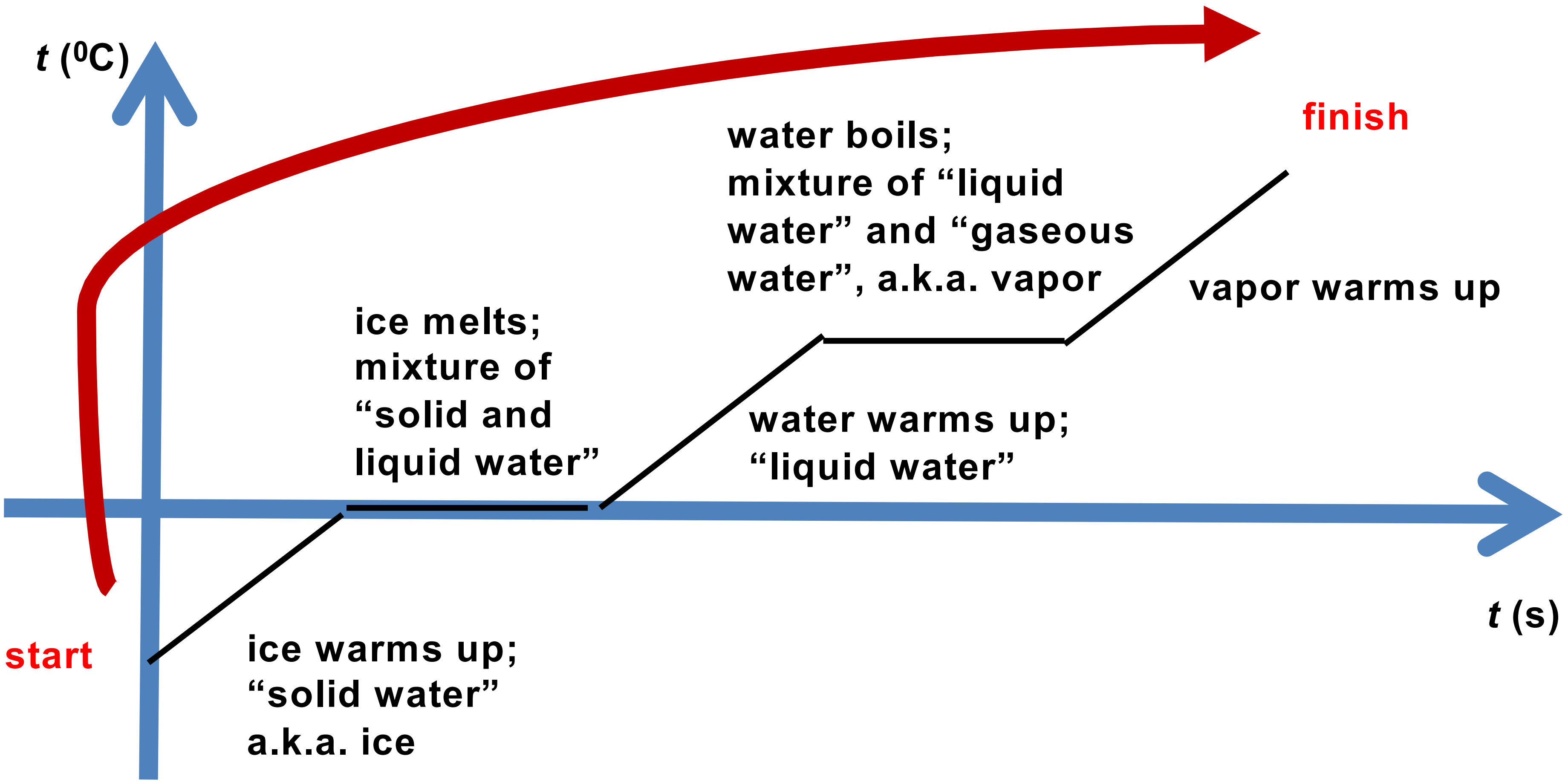
1. This statement is correct
2. This statement is wrong
3. This statement depends on a personal views on climate change

An ice cube is taken out of a freezer and placed on a heat plate.

$$T_C = \left(\frac{5°C}{9°F}\right)(T_F - 32°F)$$



An ice cube is taken out of a freezer and placed on a heat plate (in a closed container).

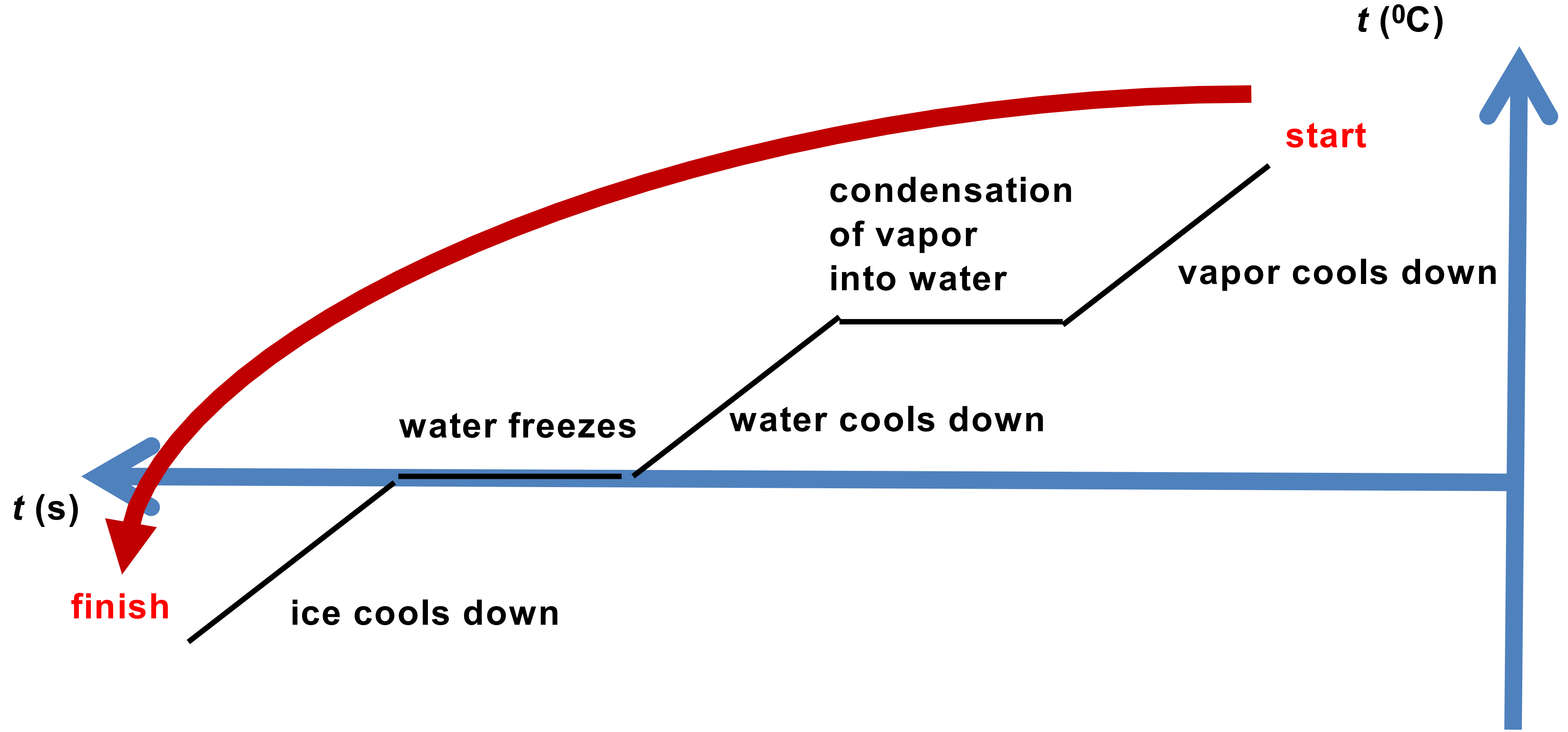


"When an ice cube is taken out of a freezer and placed on a heat plate it *immediately* starts melting"

Webassign: L22 Q5

1. **This statement is correct**
2. **This statement is wrong**
3. **This statement depends on a personal views on climate change**

Vapor (in a closed container) taken from on oven and placed into a freezer.



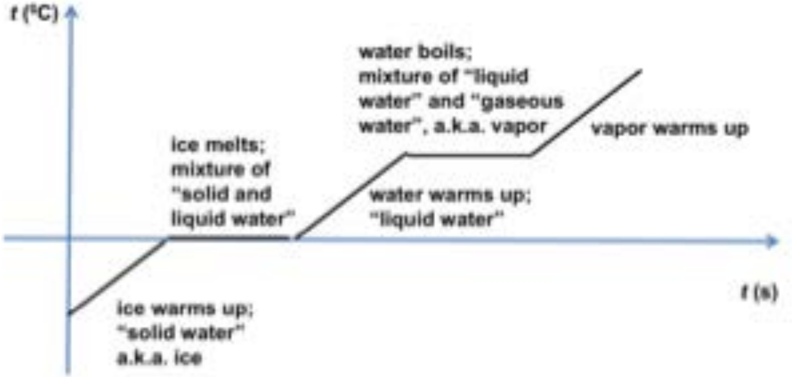
Heat

Heat exchange might lead to: (a) temperature change or (b) phase/state change/transition.

For an object changing its temperature:

Larger ΔT

More heat



For an object changing its phase (state):

More massive object

More heat

Heat exchange might lead to: (a) temperature change or (b) phase/state change/transition.

For an object changing its temperature:

$$Q = C{*}(T_f - T_i)$$

$C = Q/\Delta T$

Heat capacity of an *object*

$c = C/m$

Specific heat capacity of the *material/substance*

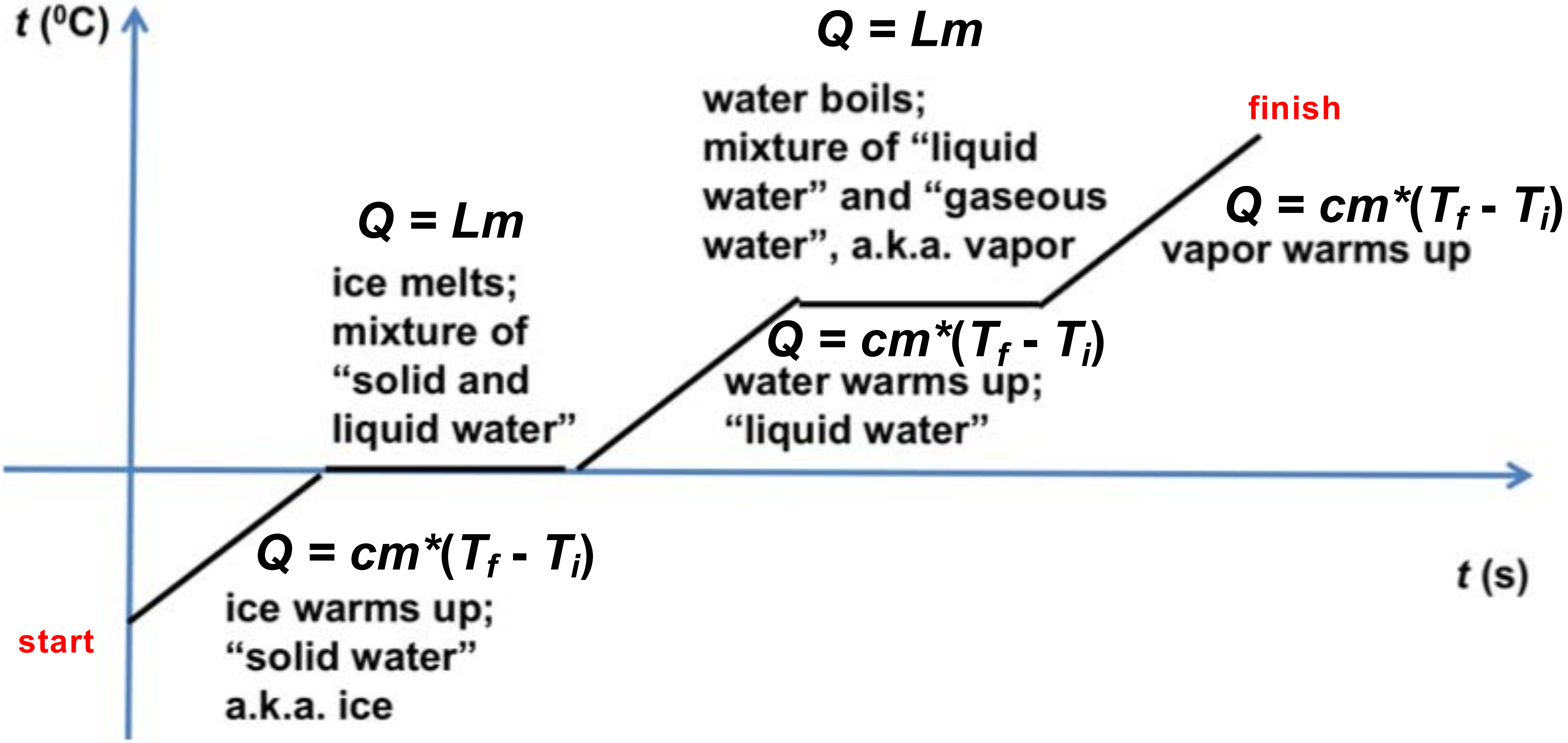
$$Q = cm{*}(T_f - T_i)$$

For an object changing its phase (state):

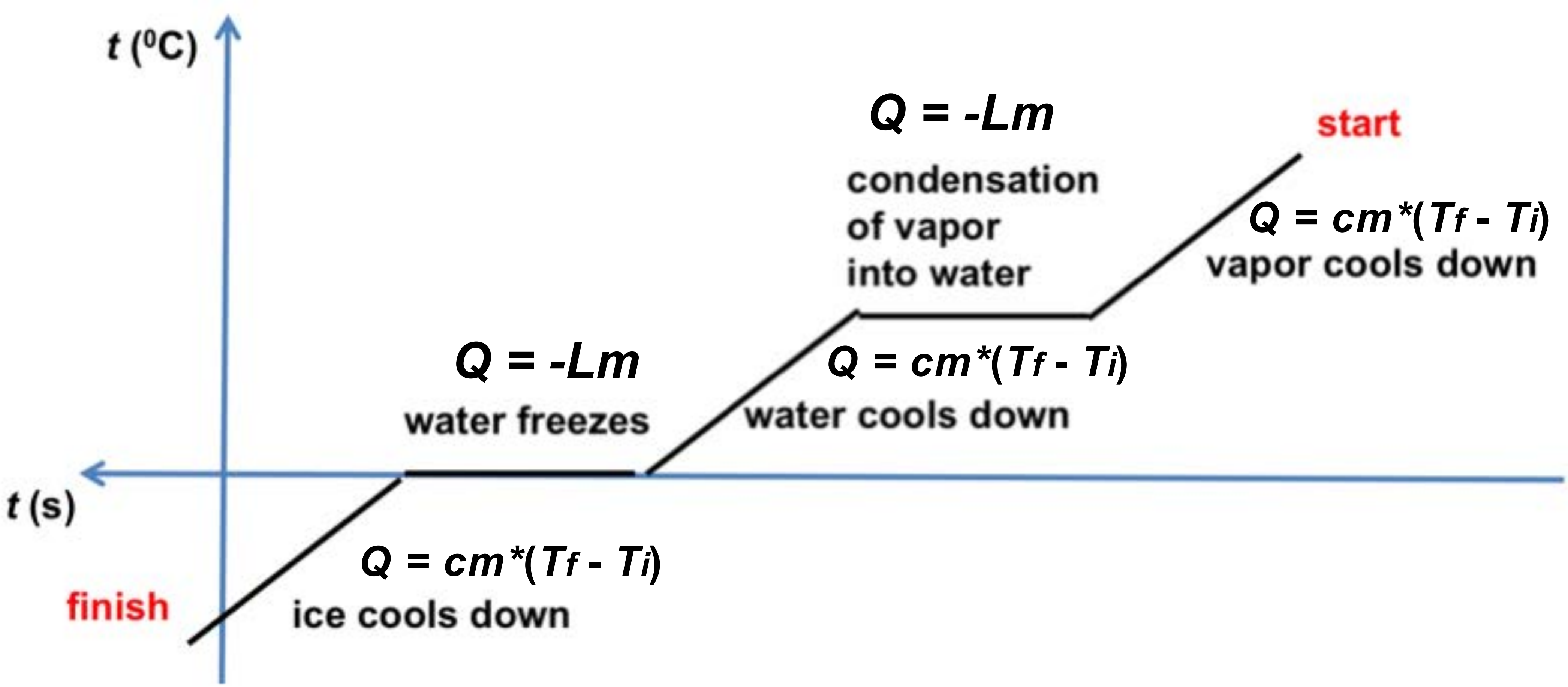
$$\boxed{|Q| = Lm}$$

Latent heat of substance

Absorbing heat



Releasing heat



"Heat" for A change of state

Freezing or melting: $|Q| = mL_f$
where L_f is the latent heat of fusion

Boiling or condensing: $|Q| = mL_v$
where L_v is the latent heat of vaporization

$$Q = \pm Lm$$

(+ is for absorbing *Q*
- Is for releasing *Q*)

For an object changing its temperature:

$$Q = C * (T_f - T_i)$$

Heat capacity of an object

Absorbing: $Q > 0 \Leftrightarrow T_f > T_i$

Releasing: $Q < 0 \Leftrightarrow T_f < T_i$

For an object changing its phase (state):

Absorbing *(melting, boiling)*: $Q = +Lm > 0$

Releasing *(freezing, condensing)*: $Q = -Lm < 0$

Latent heat

We need to select + or -

“Heat” for a temperature change

“Heat” is energy transferred between a system and its surroundings because of a temperature difference between them.

$$Q = C(T_f - T_i) = cm(T_f - T_i)$$

$\boxed{C = cm \text{ is heat capacity of an } \textit{object}}$

$\boxed{c = C/m \text{ is specific heat capacity of a } \textit{substance}}$

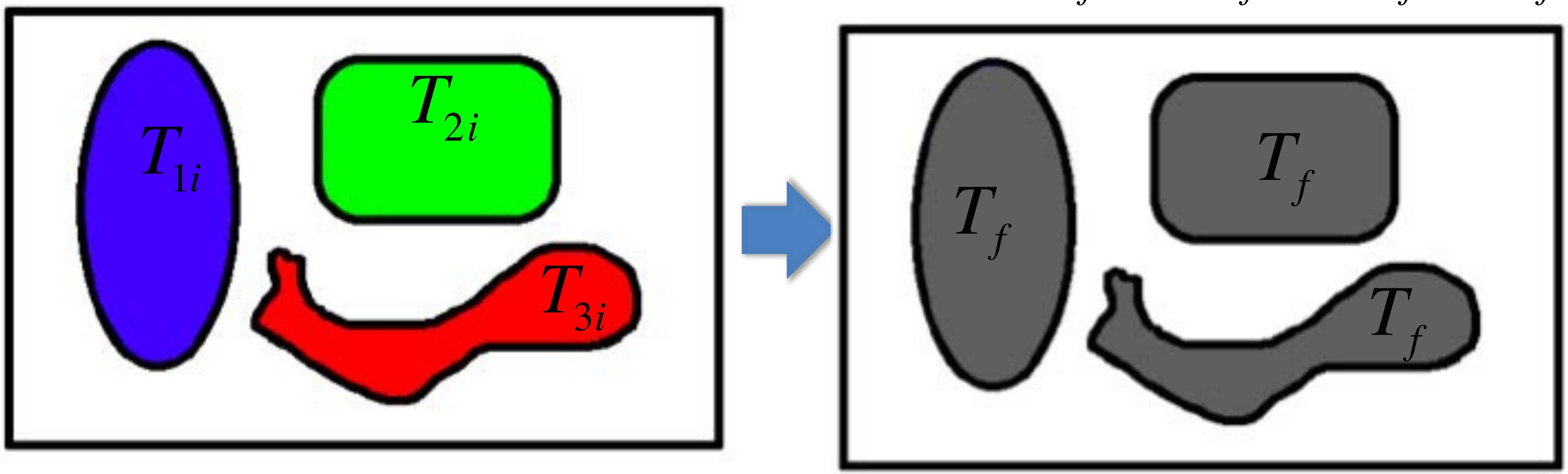
Specific heat

$$c = \frac{Q}{m(T_f - T_i)} = \frac{Q_{11}}{1 \cdot 1}$$

Material	c (J/(kg °C))	Material	c (J/(kg °C))
Aluminum	900	Water (gas)	1850
Copper	385	Water (liquid)	4186
Gold	128	Water (ice)	2060

Thermal equilibrium

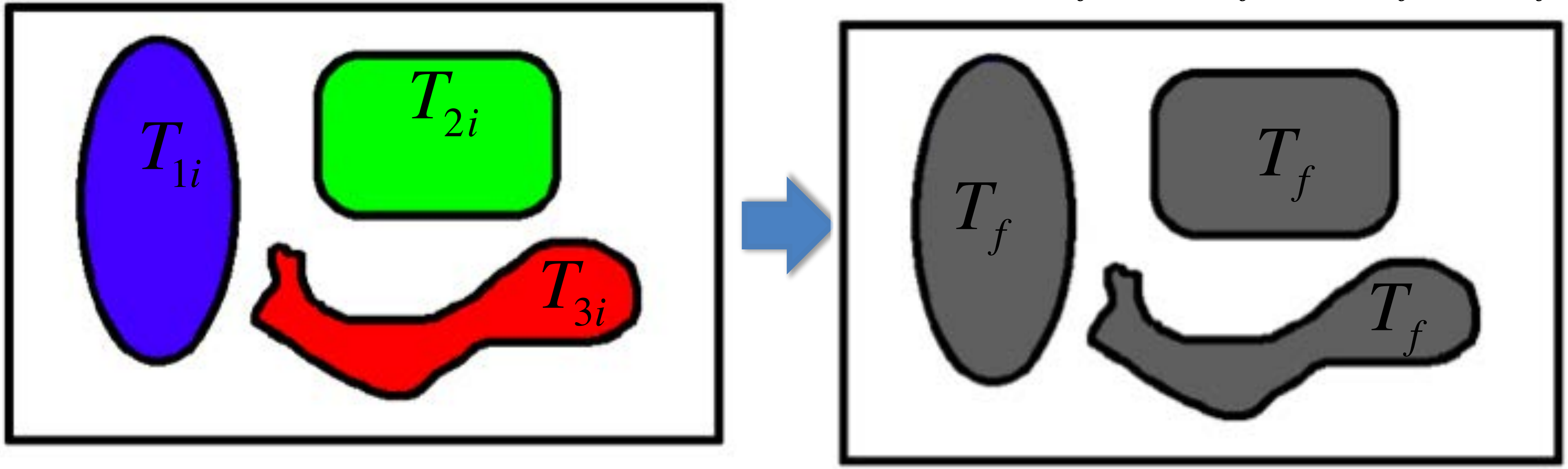
$$T_{1f} = T_{2f} = T_{3f} = T_f$$



1. Insulated (isolated) system (there is NO heat exchange with the surroundings; No heat exchange with the *outside* world
2. No mechanical work is done

Thermal equilibrium

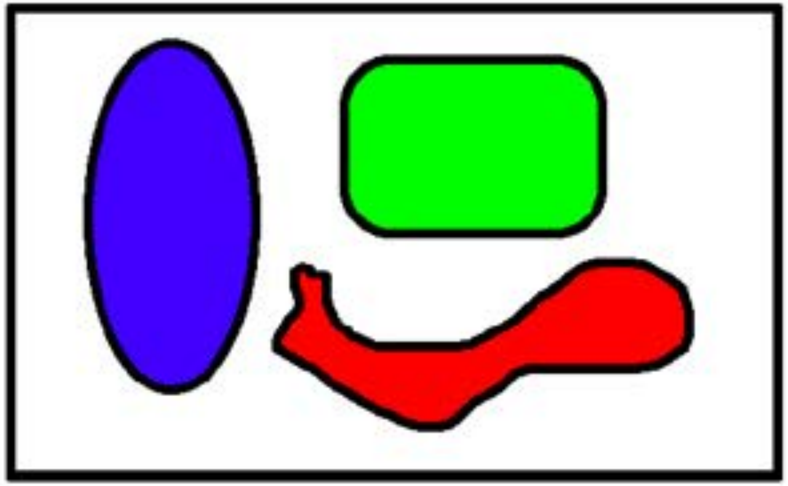
$$T_{1f} = T_{2f} = T_{3f} = T_f$$



$$\Sigma Q = Q_1 + Q_2 + Q_3 + \ldots = 0$$ **LCE**

or

$$\Sigma |Q|_{Absorbed} = \Sigma |Q|_{Released}$$ **HBE**



When an object absorbs some heat (internal energy increases) => Q > 0

When an object emits (looses) some heat (internal energy decreases) => Q < 0

The summary for HW3P3

$$\Sigma Q = Q_1 + Q_2 + Q_3 + \ldots = 0$$ *For an insulated system*

Heating, cooling $Q = cm(T_f - T_i)$ (you get the right sign automatically)

Melting $Q = mL_f$ Freezing $Q = -mL_f$

Boiling $Q = mL_v$ Condensing $Q = -mL_v$

ALWAYS!

READY TO FINISH!

PY105 HW3 P3 (9141547)

Previewer Tools

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Show: All, None ☑ Assignment Score ☑ Key ☑ Solution ☑ Help/Hints ☑ Mark ☐ Answer Format Tips

Current Score: 0/12 **Due:** Thu Jun 30 2016 11:00 PM EDT

Question	1	2	3	4	5	6	7	8	Total
Points	0/2	0/1	0/2	0/2	0/2	0/1	0/1	0/1	0/12

Untitled — Edited

5. 0/2 points OSColPhys1 14.P.019.WA. [2611628]

A 2.83-g lead bullet traveling at 428 m/s strikes a target, converting its kinetic energy into thermal energy. Its initial temperature is 40.0°C. The specific heat is 128 J/(kg · °C), latent heat of fusion is 24.5 kJ/kg, and the melting point of lead is 327°C.

(a) Find the available kinetic energy of the bullet.

A 10 g lead bullet travels at 100 m/s. The initial temperature of the bullet is 20° C.

Then the bullet hits a target and stops.

Will the bullet melt?

Webassign: L22 ~~Q6~~

1. Yes!
2. NO!
3. We need more information!

A 10 g lead bullet travels at 100 m/s. The initial temperature of the bullet is 20° C. Then the bullet hits a target and stops.

Will the bullet melt?

1. Yes!
2. NO!
3. We need more information!

Webassign: L22 Q5

$v = 100\ m/s$

i

f

$V_f = 0;\ KE_f = 0$

$KE_i = \frac{mv^2}{2} = \frac{0.01 \cdot 100^2}{2} = 50\ J$

$KE_i = Q$

$\Downarrow$

$Q = 50\ J$

A 10 g lead bullet travels at 100 m/s. The initial temperature of the bullet is 20° C.
Then the bullet hits a target and stops.

Will the bullet melt?

1. Yes! 2. NO!

3. We need more information!

Product	Latent Heat (kJ/kg)
Lead	22.4

$$Q = mL_f$$

$\boxed{621.5°F\ (327.5°C)}$

Lead, Melting point

$$Q = cm(T_f - T_i)$$

Substance	c in J/gm K
Lead	0.128

$$c = \frac{Q}{m\Delta T} = \frac{J}{kg\,K}$$

$$c = 0.128\ \frac{J}{gm\,K} = 128\ \frac{J}{kg\,K}$$

$$\frac{\cancel{m}v^2}{2} = c\cancel{m}\,\Delta T$$

$$\Delta T = \frac{v^2}{2\cdot c} = \frac{100^2}{2\cdot 128} = 39\ K\ \text{or}\ C$$

$$t_i = 20°C\ ;\ t_f = t_i + \Delta t = 20 + 39 = 59°$$

A change of state : WATER/ice

For water the values are:

L_f = 333 kJ/kg   water ✕ ice

L_v = 2256 kJ/kg   water ✕ vapor

c_{liquid} = 4.186 kJ/(kg °C)

c_{Ice} = 2.09 kJ/(kg C)

$$Q = \pm Lm$$

$$Q = cm(T_f - T_i)$$

Convenient approximations:

c_W = 4000 J/(kg °C); c_{ice} = 2000 J/(kg °C);

L_f = 300000 J/kg; L_v = 2000000 J/kg;