Physics 131- Fundamentals of Physics for Biologists I

Professor: Arpita Upadhyaya

Intermolecular Interactions

Heat, Temperature

End of term logistics

- Please be sure to fill out the post-semester survey! Link (ELMS and in emails):

  http://tinyurl.com/SP14-Phys131-End-Survey

- **Final Exam in this room + next room: Saturday, May 17, 6:30-8:30 pm**

- Final Exam review Wed (reading day) here, time to be announced
- Exam cumulative up to today; equally distributed (as best as possible) in questions
- Exam much like a midterm x 2 in length

For the final!

- Review slides will soon be posted as a link on the Schedule page
- Grades for Readings, Clickers, and HW
  will be updated and posted in the next few days.
- Sample problems will be posted
- Do you want office hours this week?

Foothold ideas: Potential Energy

- For some forces work only depends on the change in position. Then the work done can be written

$$\vec{F} \cdot \Delta\vec{r} = -\Delta U$$

U is called a *potential energy*.

- For gravity, $U_{gravity} = mgh$

For a spring, $U_{spring} = \frac{1}{2} kx^2$

For electric force, $U_{electric} = k_C Q_1 Q_2 / r_{12}$

Moving to molecules

- Apply our Newtonian framework and results to atoms and molecules.
- See what goes over directly, what we have to add.
- Can we integrate what we know about atoms and molecules from chemistry with the physics we have learned?

Foothold ideas: Energies between charge clusters

- Atoms and molecules are made up of charges.
- The potential energy between two charges is

$$U_{12}^{elec} = \frac{k_C Q_1 Q_2}{r_{12}}$$

No vectors!

- The potential energy between many charges is

$$U_{12\ldots N}^{elec} = \sum_{i<j=1}^{N} \frac{k_C Q_i Q_j}{r_{ij}}$$

Just add up all pairs!

Foothold Ideas: Conservation of Mechanical Energy

- Total of kinetic plus potential energy are conserved if resistive forces can be ignored

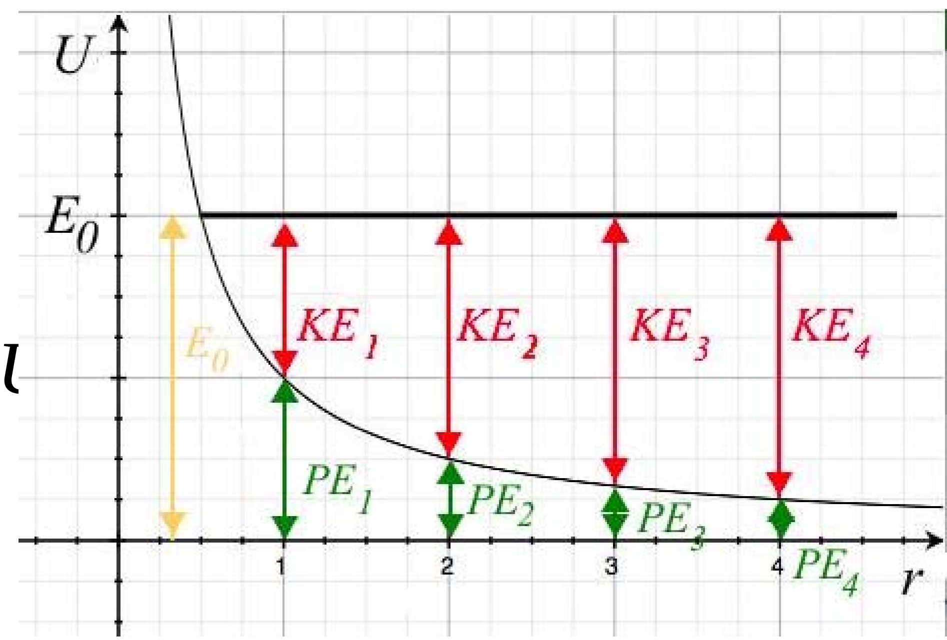
Mathematical Representation

$$\Delta(\tfrac{1}{2}mv^2) = \Delta U$$

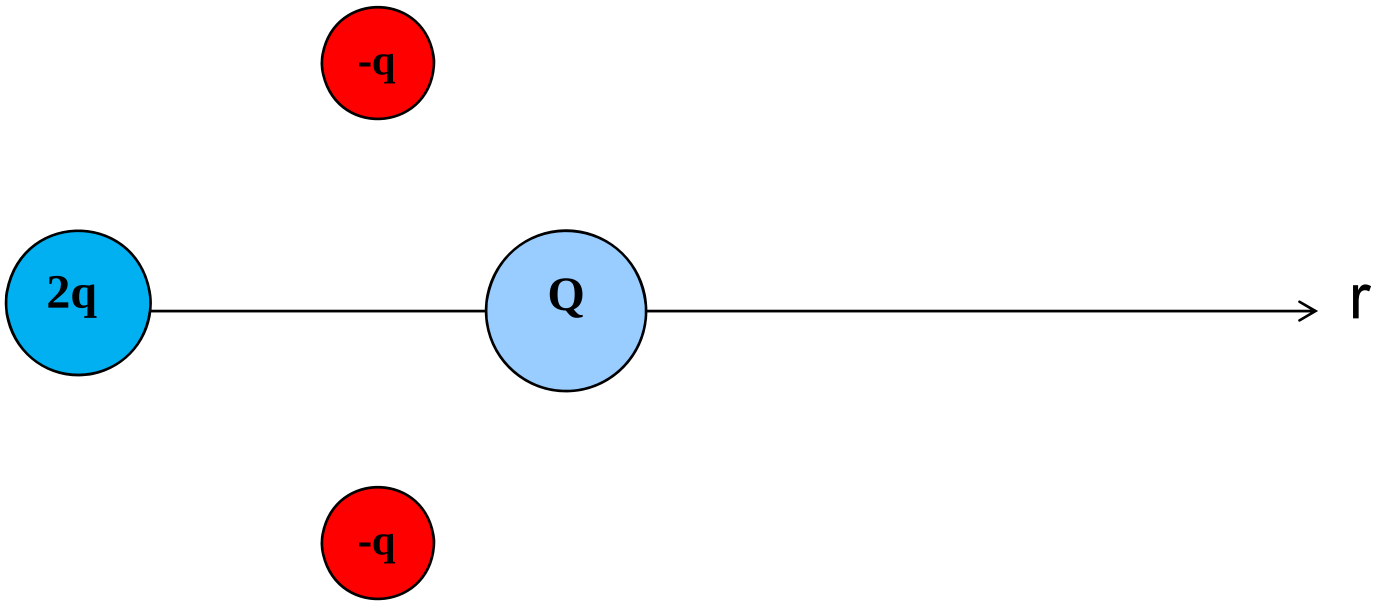
$$\Delta(\tfrac{1}{2}mv^2 + U) = 0$$

$$\tfrac{1}{2}mv^2_{initial} + U_{initial} = \tfrac{1}{2}mv^2_{final} + U$$

Graphical Representation

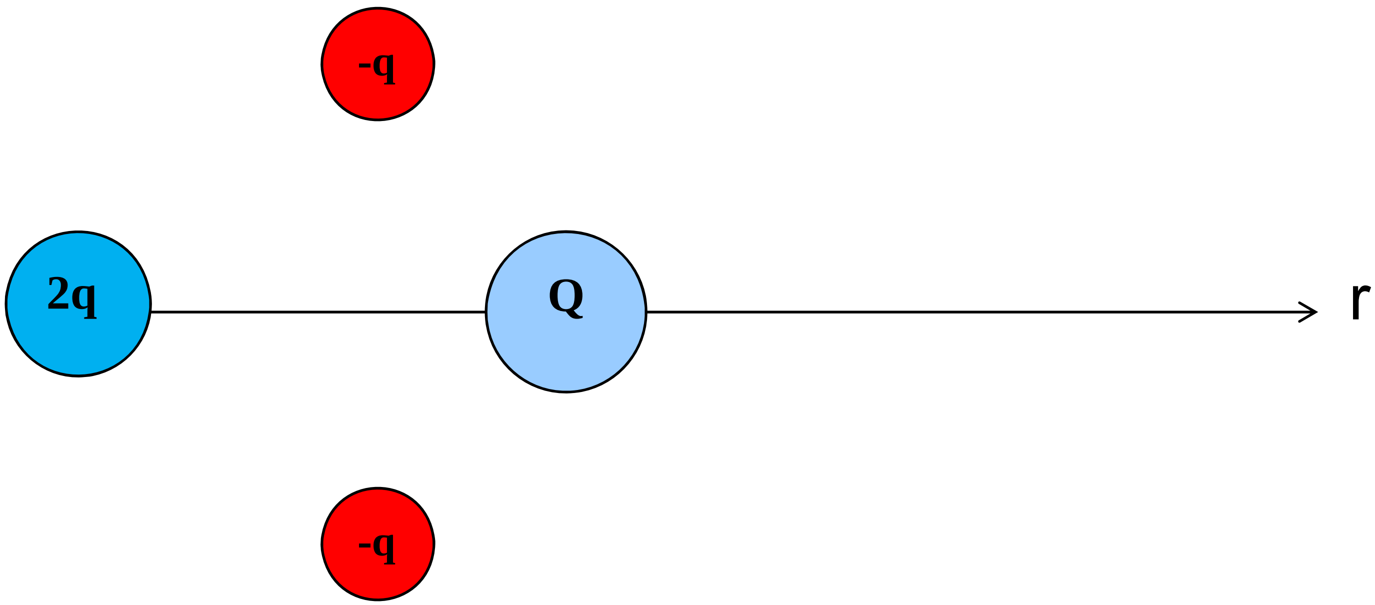


How many interactions in the system have an electric potential energy? (Equivalently: How many "1/r" terms will we have to add up to get the total electric PE?)



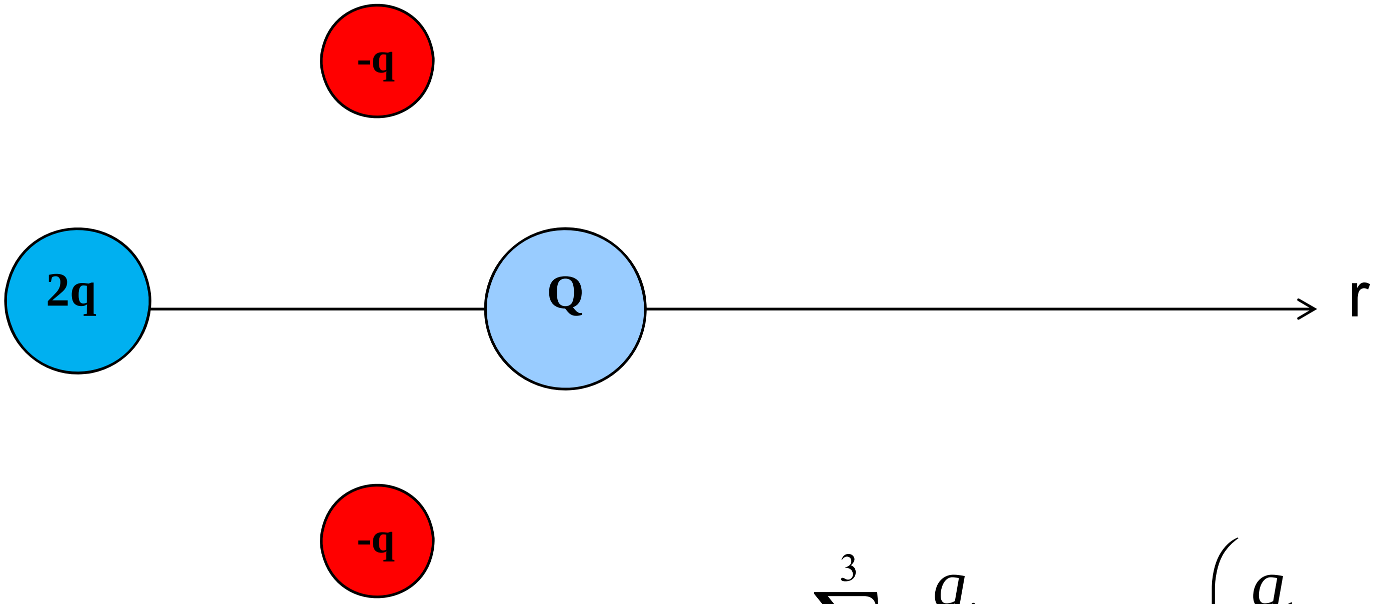
Answer: 6

How many of those potential energies change when the charge Q moves to the right?

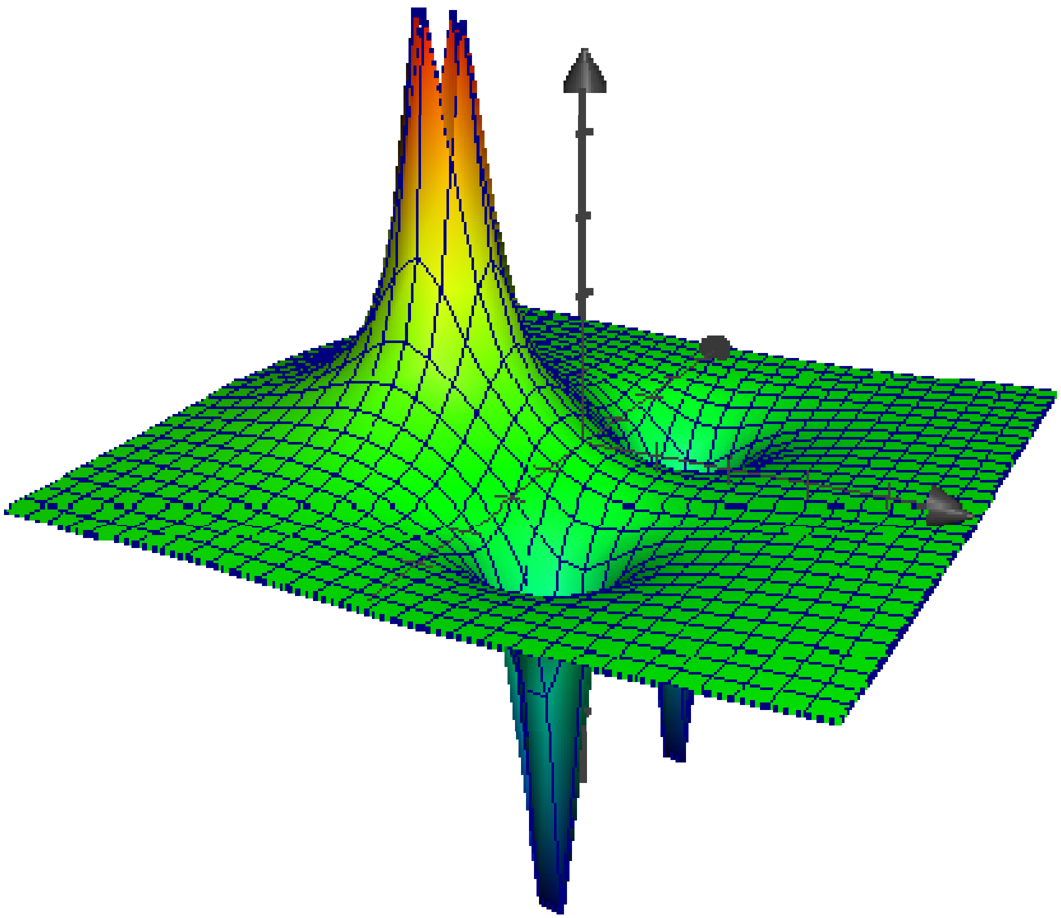


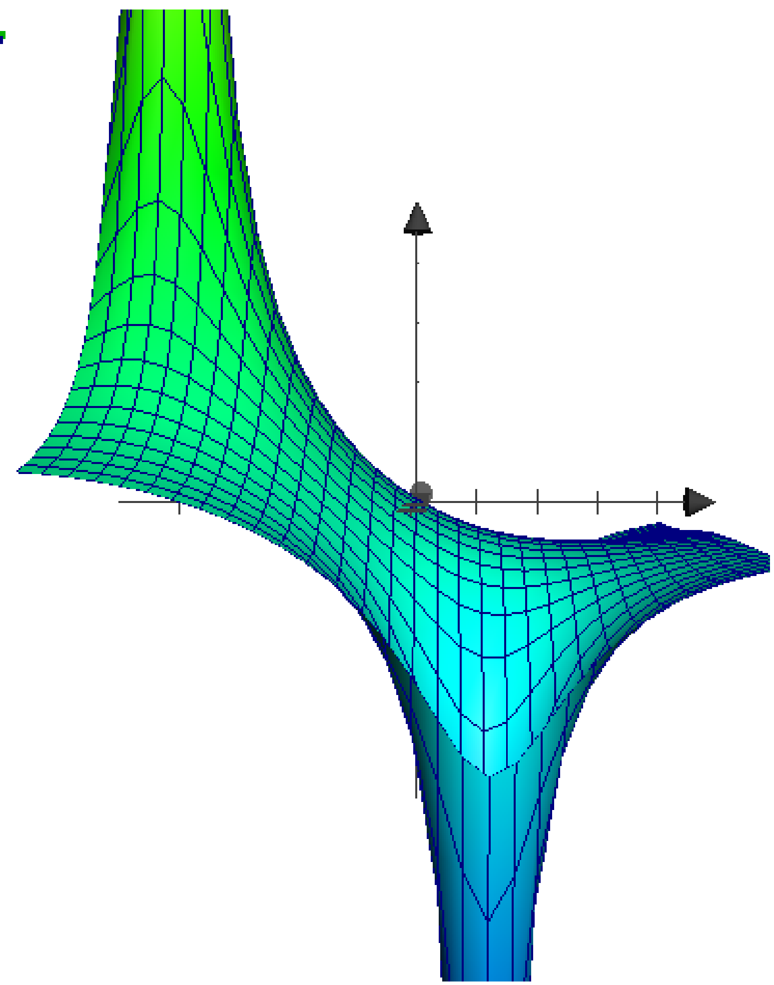
Answer: 3

Sketch a graph of the extra potential energy from adding *Q* as a function of position *r* of charge *Q*



$$\Delta U = k_C Q \sum_{i=1}^{3} \frac{q_i}{r_{Q \to q_i}} = k_C Q \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} \right)$$





Foothold ideas:
Forces from PE

- For conservative forces, PE can be defined by

$$\vec{F} \cdot \Delta\vec{r} = -\Delta U$$

- If you know *U*, the force can be obtained from it via

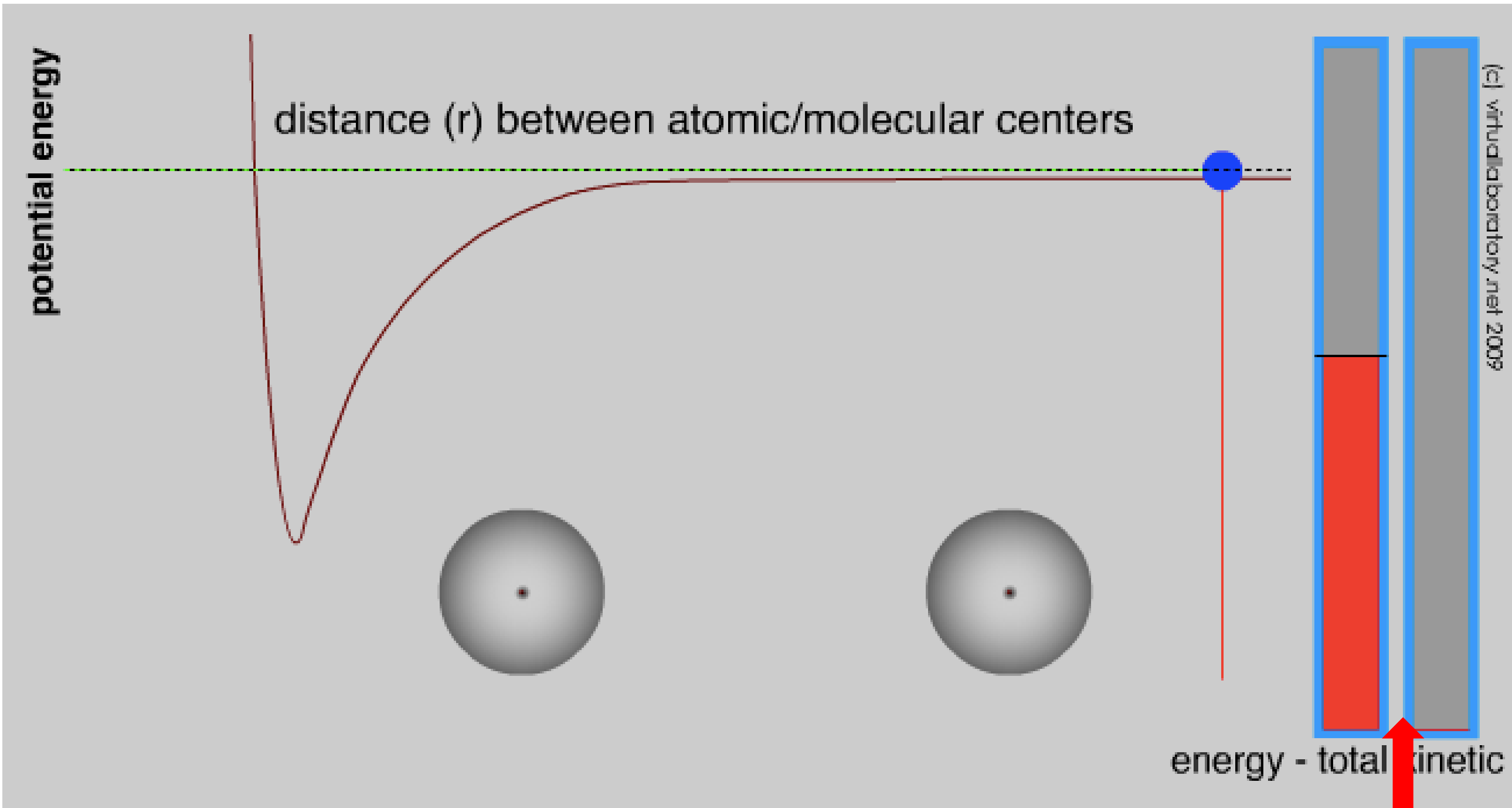
$$F_{\parallel}^{type} = -\frac{\Delta U_{type}}{\Delta r} = -\frac{dU_{type}}{dr}$$

- In more than 1D need to use the *gradient*

$$\vec{F}^{type} = -\left(\frac{\partial U_{type}}{\partial x}\hat{i} + \frac{\partial U_{type}}{\partial y}\hat{j} + \frac{\partial U_{type}}{\partial z}\hat{k}\right) = -\vec{\nabla} U_{type}$$

- The force always points <u>down</u> the PE hill.

Balance of kinetic and potential energy in a molecule



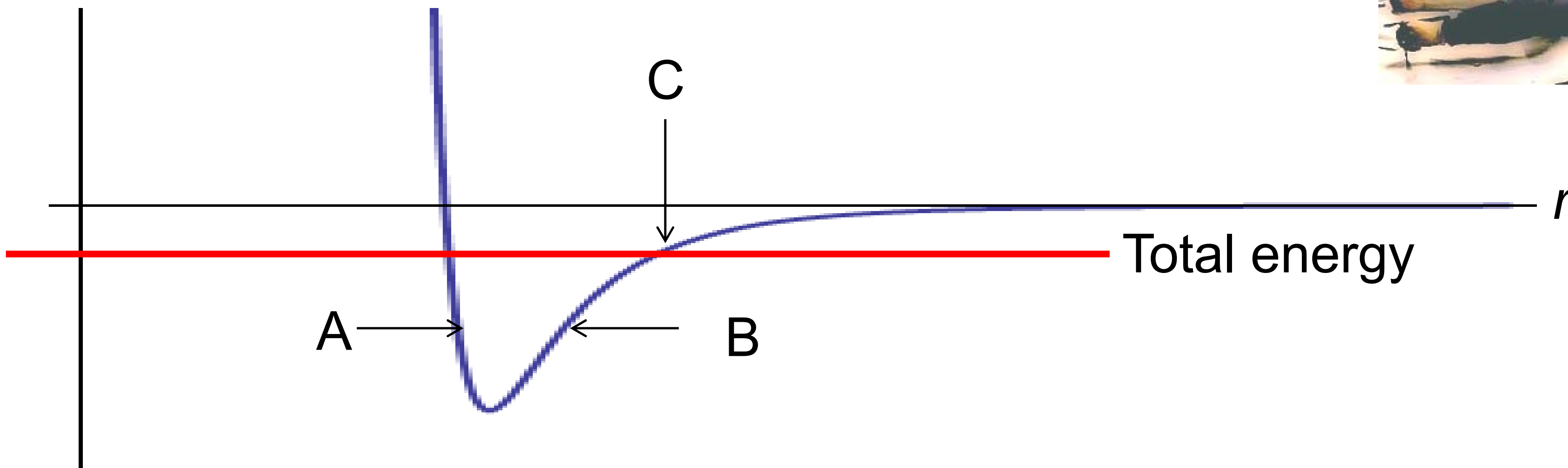
http://besocratic.colorado.edu/CLUE-Chemistry/activities/LondonDispersionForce/1.2-interactions-0.html

Page 3 of the interactive Demo!

Energy Bar graphs!

Foothold ideas: Bound states

- When two objects attract, they may form a *bound state* – that is, they may stick together.
- If you have to do positive work to pull them apart in order to get to a separated state with KE = 0, then the original state was in a state with negative energy.



What is the **velocity** and **force** at point A,B,C Consider both magnitude and direction!

Draw the vectors on the whiteboard

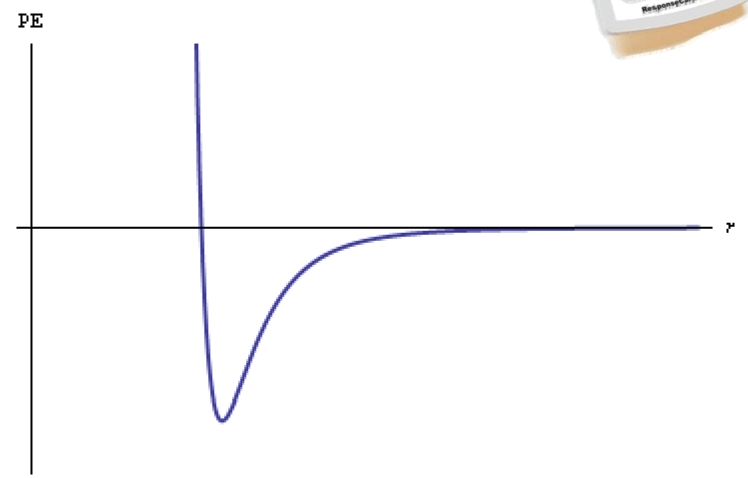
F_A (pointing right) > F_B (pointing left) > F_C (pointing left)

$v_A = v_B$ (as KE is the same, direction undefined)

$v_C = 0$

You know that two atoms that are far apart are barely interacting.

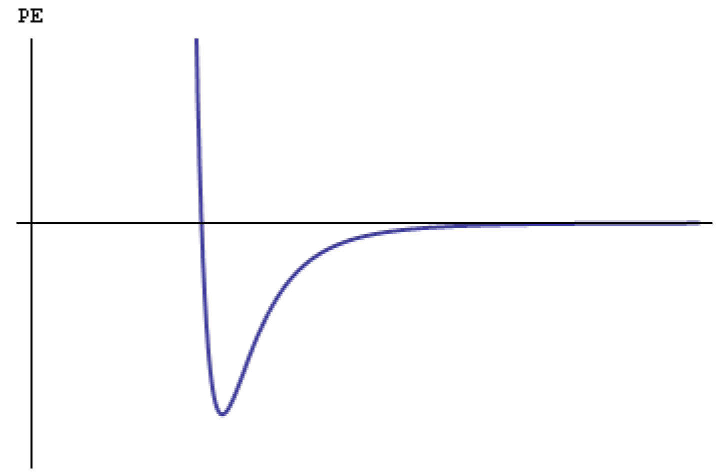
How is this represented visually in the PE diagram?



1. The potential energy approaches zero as *r* gets large.
2. The PE curve is close to horizontal as *r* gets large.
3. The PE curve is close to vertical as *r* gets small.
4. The potential energy has a minimum.
5. More than one of these
6. The PE diagram doesn’t demonstrate this information
7. None of these

These two atoms can exist in a stable bound state.

How is this represented visually in the PE diagram?



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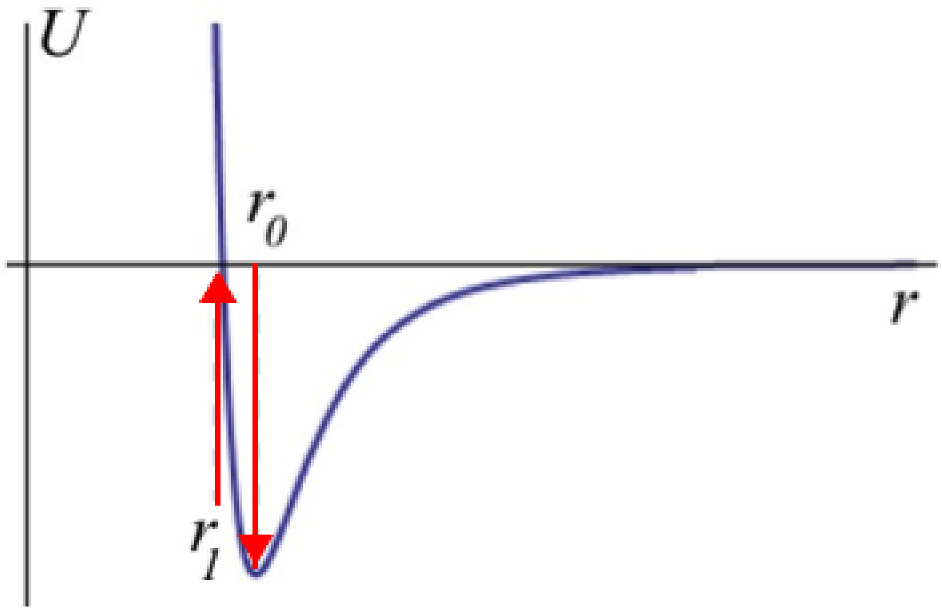
3. The PE curve is close to vertical as *r* gets small.
4. The potential energy has a minimum.
5. More than one of these
6. The PE diagram doesn't demonstrate this information
7. None of these

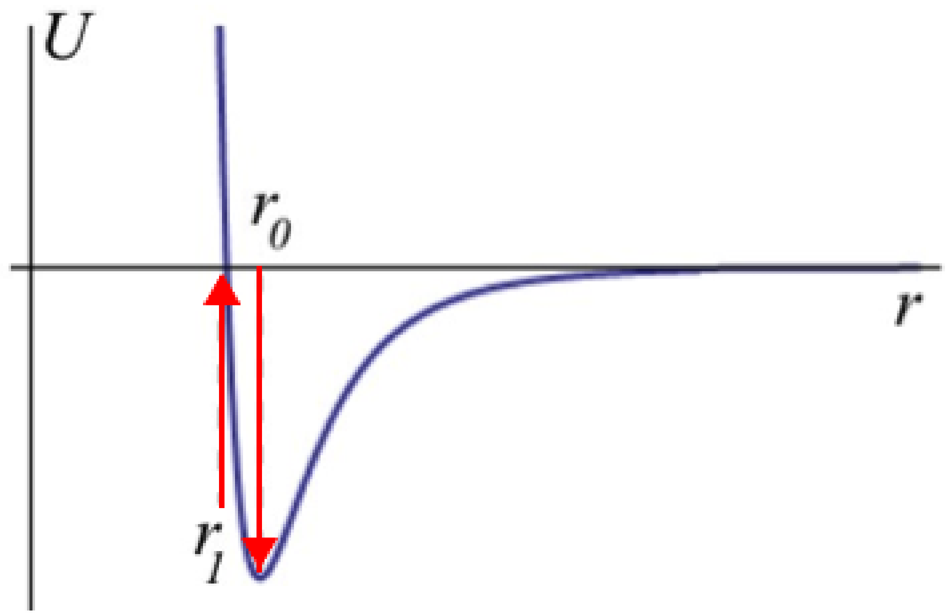
The figure shows the potential energy of two interacting atoms. The point with the minimum value is r_0 and the point where the curve crosses 0 is r_1. Where is the force between the two atoms the largest?

1. At r_0.
2. At r_1.
3. At fairly large values of r.



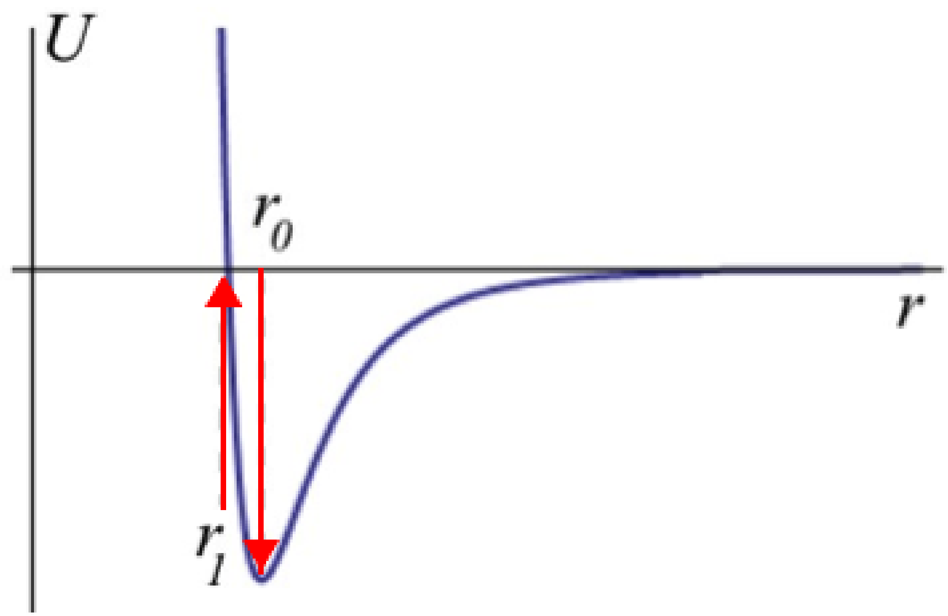
The figure shows the potential energy of two interacting atoms. The point with the minimum value is r_0 and the point where the curve crosses 0 is r_1. Where is the force between the two atoms repulsive?

1. Between r_1 and r_0.
2. Between r_0 and ∞.
3. Nowhere.

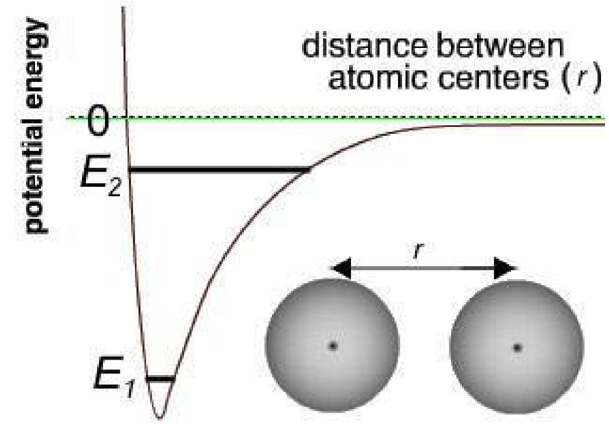


The figure shows the potential energy of two interacting atoms. The point with the minimum value is r_0 and the point where the curve crosses 0 is r_1. Where is the force between the two atoms attractive?

1. Between r_1 and r_0.
2. Between r_0 and ∞.
3. Nowhere.



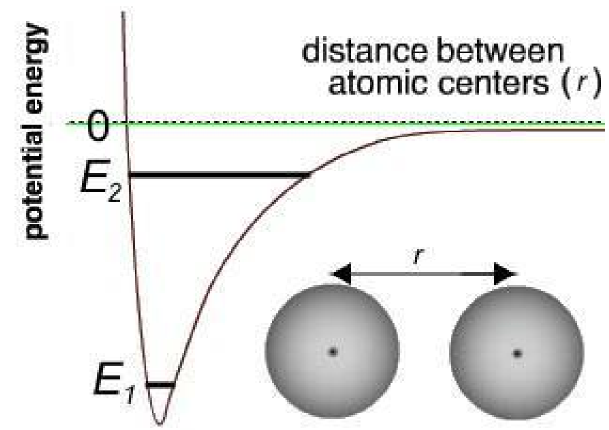
Two atoms interact with a potential energy between them that varies as a function of their separation as shown in the graph at the right. We take the zero of energy to be when they are very far apart and at rest. They have a total energy E_1 as shown on the figure. Which of the following statements are true about them?



A. They are in a bound state.
B. The total energy of the molecule is positive.
C. The total energy of the molecule is negative.
D. The total energy of the molecule is zero.

1. Only A
2. A and B
3. A and C
4. A and D
5. Only B
6. Only C
7. Only D

Two atoms interact with a potential energy between them that varies as a function of their separation as shown in the graph at the right. We take the zero of energy to be when they are very far apart and at rest. They have a total energy E_1 as shown on the figure. Which of the following statements are true about them?



1. To pull them apart, you would have to put in an energy E_1.
2. To pull them apart, you would have to put in an energy $-E_1$.
3. By pulling them apart, you would gain an energy E_1 that you could use elsewhere.
4. By pulling them apart, you would gain an energy $-E_1$ that you could use elsewhere.

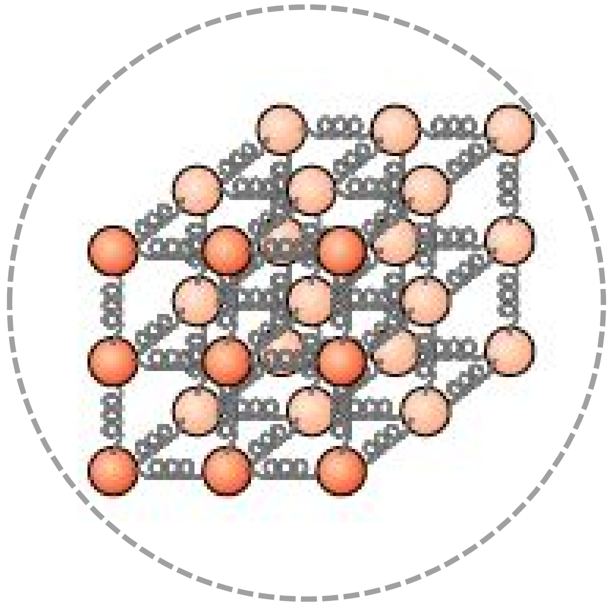
Heat

Heat is internal motion

- We have a natural sense of hot and cold.
- 19th century we realized warmth of an object is a measure of random internal motion of the object's atoms/molecules
- Realized a surprisingly large amount of this hidden energy that "hot" objects possessed, under the right conditions, could be put to work.

Hidden Energy Inside Objects

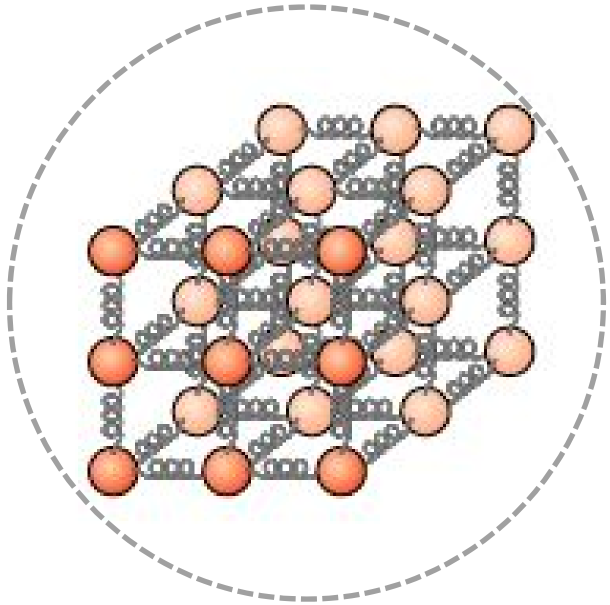
Object A



- Each atom can have kinetic energy
- Each interaction between atoms can store potential energy
  - Interactions between atoms can be modeled as springs
  - More realistic (but not perfect): Lenard-Jones Potential

Temperature and Energy

Object A



- **Temperature:** Measures amount of energy ***in each interaction*** – the key concept is that thermal energy is on average **equally distributed among all these possible locations where energy could reside. (Equipartition Theorem)**
- **Internal Energy of object A:** Measures the TOTAL energy in the whole object. Depends on temperature **and** the number of locations where energy could reside (“hide”)

Specific Heat and Heat Capacity

- The amount of thermal energy Q needed to produce one degree of temperature change is an object is called its heat capacity C.

$$Q = C\Delta T$$

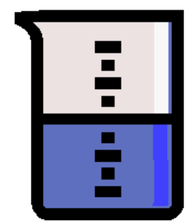
- The amount of thermal energy *per unit mass* needed to produce one degree of temperature change in an object is called its specific heat.

$$C = mc$$

Critical Experiment 1

If we have equal amounts
of the same kinds
of materials at different
temperatures
and put them together,
what happens?

200 g of
water
at 80 °C



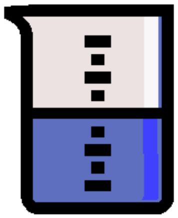
200 g of
water
at 20 °C

1. pretty close to 50 C
2. pretty close to 80 C
3. pretty close to 20 C
4. greater than 80 C
5. less than 20 C

Critical Experiment 2

If we have unequal amounts of the same kinds of materials at different temperatures
and put them together, what happens?

100 g of water at 80 °C

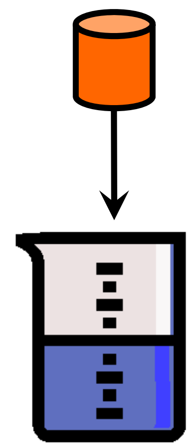


200 g of water at 20 °C

1. pretty close to 40 C
2. pretty close to 80 C
3. pretty close to 20 C
4. greater than 60 C
5. something else

Experiment 3

If we have equal masses of different kinds of materials at different temperatures and put them together, what happens?



200 g of copper at 80 °C

200 g of water at 20 °C

1. pretty close to 50 C
2. pretty close to 80 C
3. pretty close to 20 C
4. greater than 80 C
5. less than 20 C

Whiteboard, TA & LA

Why does a mass of copper heat the cold water less than an equal mass of hot water at the same temperature?

Whiteboard, TA & LA

Thermal Energy is <u>NOT</u> Temperature

- Even if the masses are the same, the temperature does not wind up halfway between.
- There are different numbers of places to put the energy in water and copper!
- Each kind of material translates thermal energy into temperature in its own way.

$$Q = m_1 c_1 \Delta T_1 = -m_2 c_2 \Delta T_2$$

Specific Heat and Heat Capacity

- The amount of thermal energy needed to produce one degree of temperature change is an object is called its <u>heat capacity</u>.

$$Q = C\Delta T$$

- The amount of thermal energy per unit mass needed to produce one degree of temperature change in an object is called its <u>specific heat</u>.

$$C = mc$$

Can we feel the temperature?

– If we have a cup of hot water and a cup of cold water, can we feel the difference?

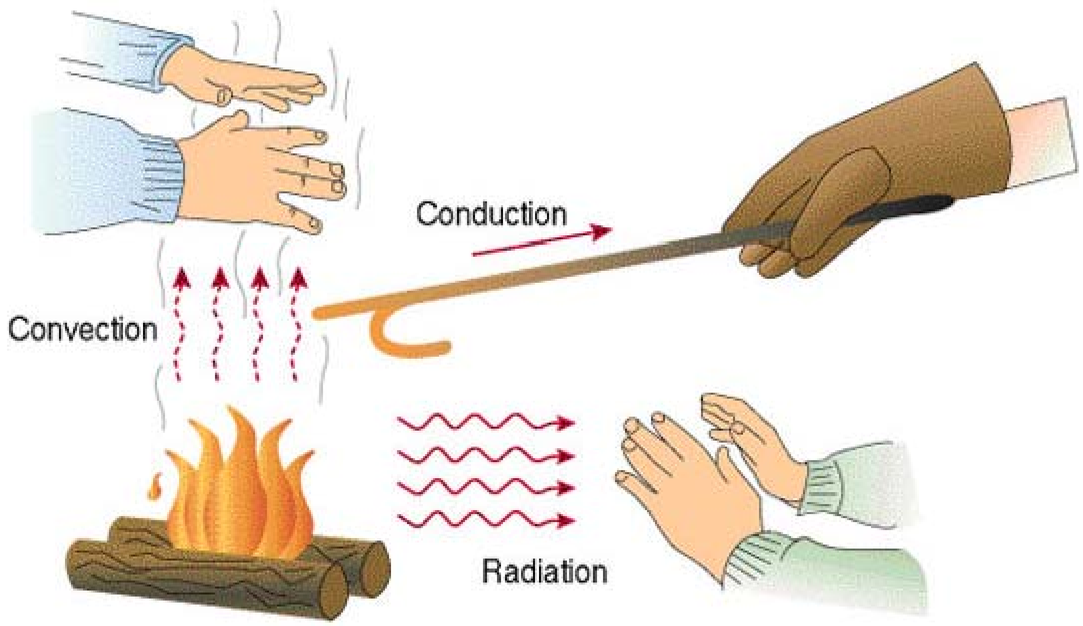
– If you touch the plastic part of your chair and the metal part, which feels warmer?

On which surface will the ice melt faster?

A. Stone
B. Copper
C. Plastic
D. Wood

Copper is the best "conductor" of heat
Heat conduction → rate of energy transfer

Heat Transfer



The objects listed in 1-3 below are placed in an oven heated to 90°C and left for a long time. Which object will feel warmest when you touch it?

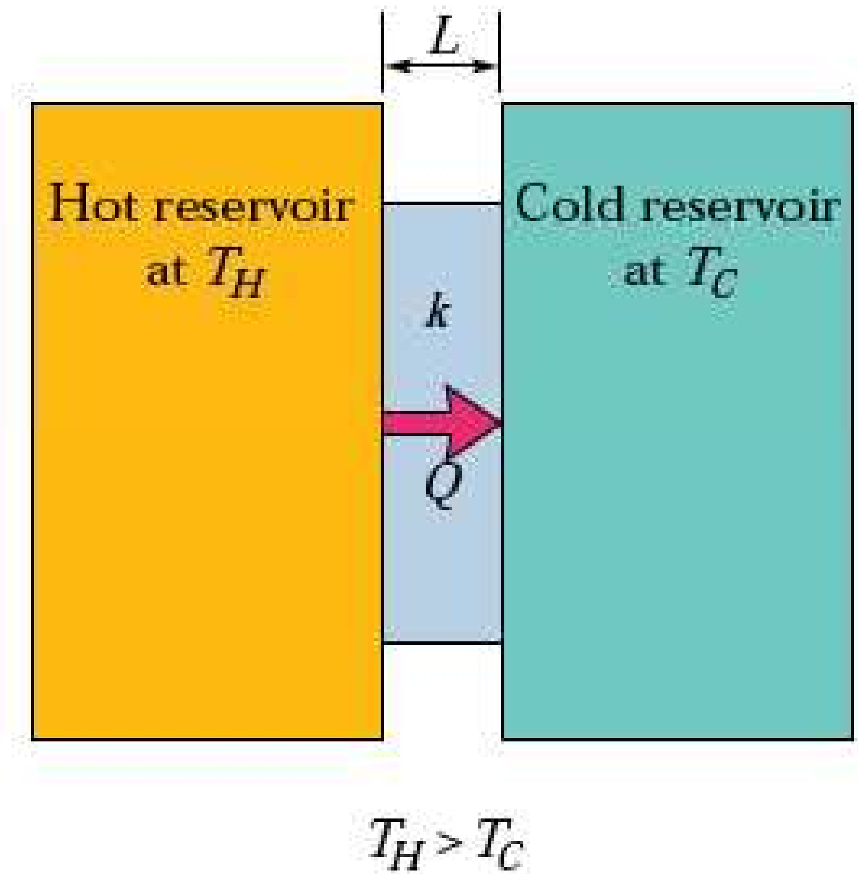
1. A ball of cotton
2. A stick of wood
3. A metal bar
4. They would all feel the same

The objects listed in 1-2-3 below are placed in an oven heated to 90^o C and left for a long time. Which object will have the highest temperature?

1. A ball of cotton
2. A stick of wood
3. A metal bar
4. They would all have the same temperature.

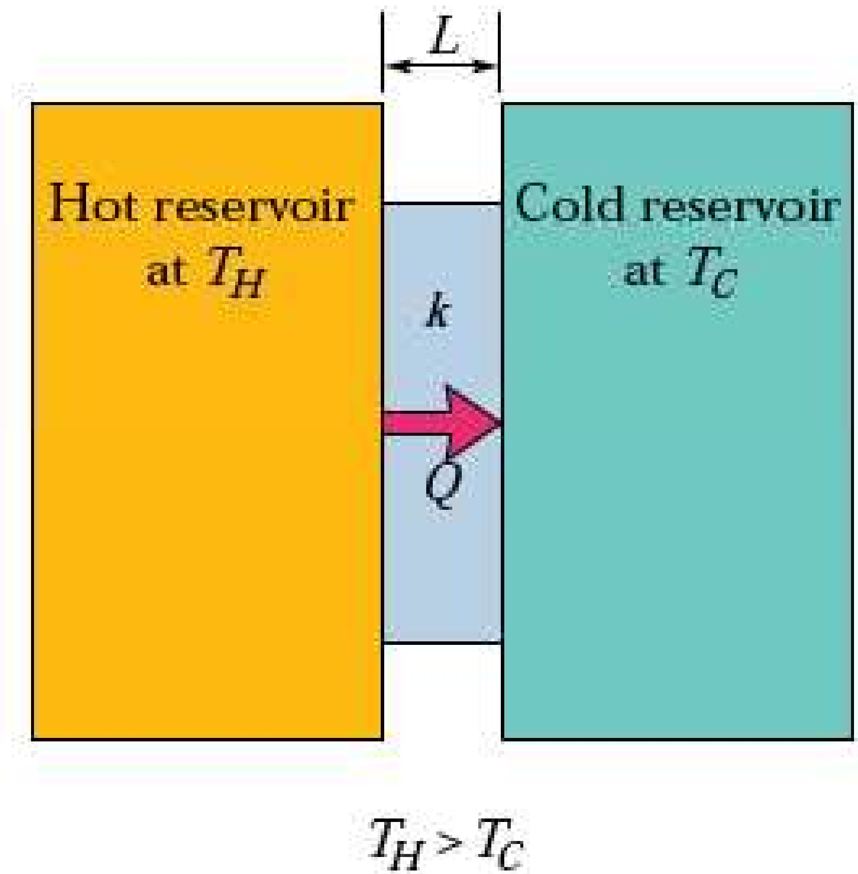
Remember diffusion?

- Why did particles spread from high density to low?
- Why do you think heat goes from warmer objects to colder?



Heat Flow by Conduction

- Simplest case (again)
  - Hot block at T_H
  - Cold block at T_C
  - Connecting block that carries ("conducts") thermal energy from the hot block to the cold.



Energy Units

- 1 calorie = energy to raise temperature of 1 gm of water by one degree C
- 1 BTU = energy required to warm 1 lb water by 1 ^{o}F
- Joule = 1 kg m^2/s^2 - Metric unit of energy
- (1 BTU is 1,055 J ~1 kJ)

Power

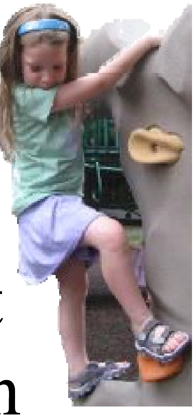
- Power = Energy per unit time
- 1 Watt = 1 Joule/s
- 1 Horsepower = 746 Watts

- 200 HP engine ~ 150 kW engine

Foothold ideas: 1

- Temperature is a measure of how hot or cold something is. (We have a natural physical sense of hot and cold.)
- When two objects are left in contact for long enough they come to the same temperature.
- When two objects of the same material but different temperatures are put together they reach an average, weighted by the fraction of the total mass.
- The mechanism responsible for the above rule is that the same thermal energy is transferred from one object to the other: Q proportional to $m\Delta T$.

Foothold ideas: 2



- When two objects of different materials and different temperatures are put together they come to a common temperature, but it is not obtained by the simple rule.
- Each object translates thermal energy into temperature in its own way. This is specified by a density-like quantity, c, the specific heat.
- The heat capacity of an object is $C = mc$.
- When two objects of different material and different temperatures are put together they reach an average, weighted by the fraction of the total heat capacity.
- When heat is absorbed or emitted by an object $Q = \pm mc\Delta T$