Office hours vote:

HW is due on Wed at 5 pm.

Office hours are on Zoom.

TA-led homework help sessions: Mon-Tue 5-8 pm.

Which time slot would work for you the best?

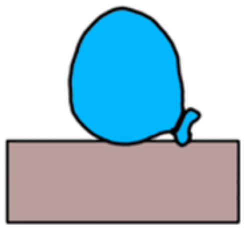
A. Mon 3:00 – 4:00 pm
B. Mon 4:00 – 5:00 pm
C. Tue 10:00 – 11:00 am
D. Tue 11:00 am – noon
E. Wed 10:00 – 11:00 am

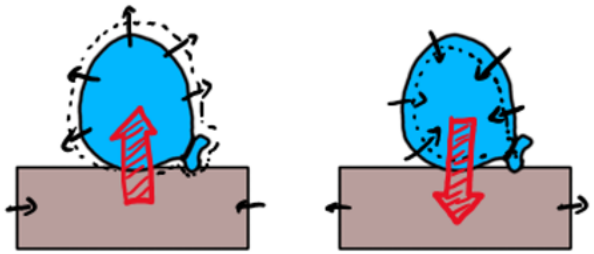
10:30 – 11:30

Lecture 2.

Temperature and Thermal equilibrium.

Zeroth law of thermodynamics.





Our starting point will be the concept of energy.

What is energy?

...The law is called the *conservation of energy*. It states that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes. ... It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same.

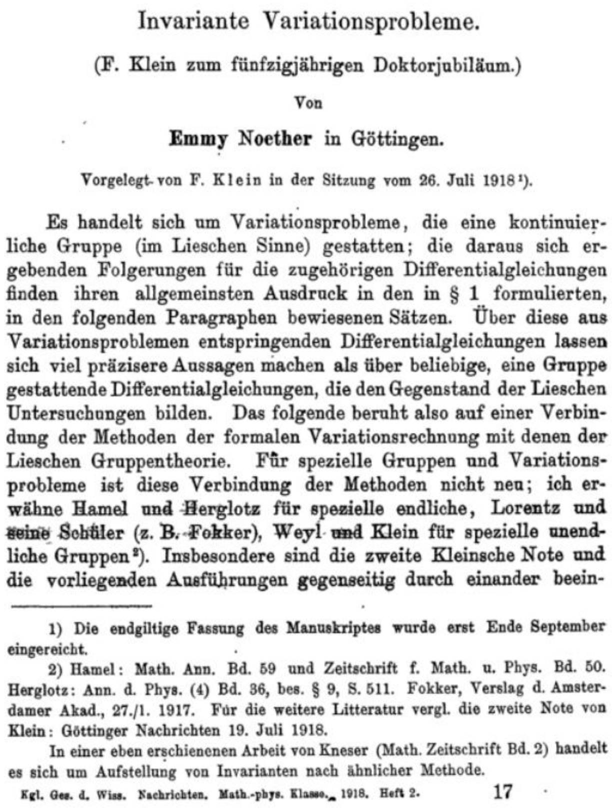
http://www.feynmanlectures.caltech.edu/I_04.html Richard Feynman, v.1, Lecture 4, “Conservation of energy”

Q: There was a person in the 20th century, who was the first person to really understand why energy is conserved. Does anyone know who it was?

Emmy Noether
(1882-1935)
Mathematician

Noether’s theorem:

- Every continuous symmetry implies a corresponding conservation law.
- In particular, time is uniform => energy conserves.



Invariante Variationsprobleme.

(F. Klein zum fünfzigjährigen Doktorjubiläum.)

Von

Emmy Noether in Göttingen.

Vorgelegt von F. Klein in der Sitzung vom 26. Juli 1918[1]).

Es handelt sich um Variationsprobleme, die eine kontinuierliche Gruppe (im Lieschen Sinne) gestatten; die daraus sich ergebenden Folgerungen für die zugehörigen Differentialgleichungen finden ihren allgemeinsten Ausdruck in den in § 1 formulierten, in den folgenden Paragraphen bewiesenen Sätzen. Über diese aus Variationsproblemen entspringenden Differentialgleichungen lassen sich viel präzisere Aussagen machen als über beliebige, eine Gruppe gestattende Differentialgleichungen, die den Gegenstand der Lieschen Untersuchungen bilden. Das folgende beruht also auf einer Verbindung der Methoden der formalen Variationsrechnung mit denen der Lieschen Gruppentheorie. Für spezielle Gruppen und Variationsprobleme ist diese Verbindung der Methoden nicht neu; ich erwähne Hamel und Herglotz für spezielle endliche, Lorentz und seine Schüler (z. B. Fokker), Weyl und Klein für spezielle unendliche Gruppen[2]). Insbesondere sind die zweite Kleinsche Note und die vorliegenden Ausführungen gegenseitig durch einander beein-

1) Die endgiltige Fassung des Manuskriptes wurde erst Ende September eingereicht.

2) Hamel: Math. Ann. Bd. 59 und Zeitschrift f. Math. u. Phys. Bd. 50. Herglotz: Ann. d. Phys. (4) Bd. 36, bes. § 9, S. 511. Fokker, Verslag d. Amsterdamer Akad., 27./1. 1917. Für die weitere Litteratur vergl. die zweite Note von Klein: Göttinger Nachrichten 19. Juli 1918.

In einer eben erschienenen Arbeit von Kneser (Math. Zeitschrift Bd. 2) handelt es sich um Aufstellung von Invarianten nach ähnlicher Methode.

Kgl. Ges. d. Wiss. Nachrichten. Math.-phys. Klasse. 1918. Heft 2. 17

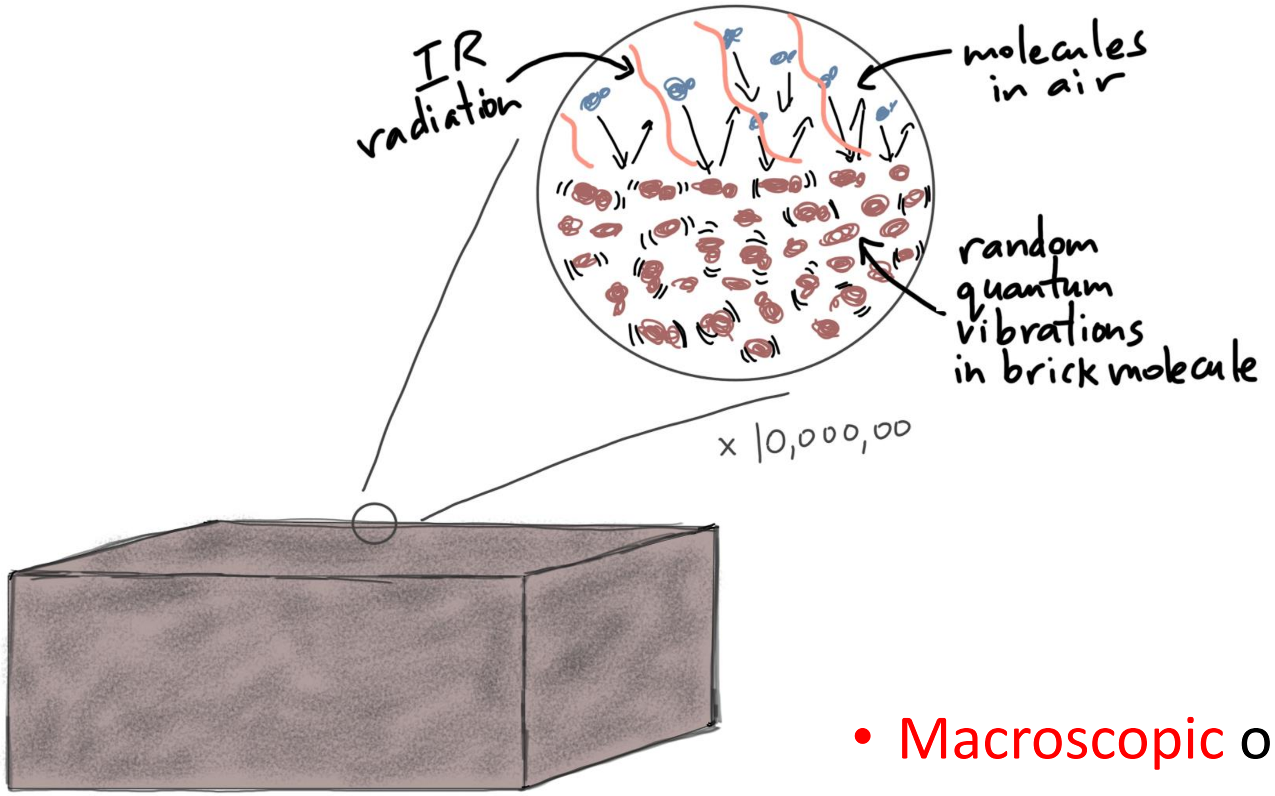
Energy (our starting point)

$\frac{mv^2}{2}$

- Energy exists in various forms: kinetic (energy of motion), potential (energy stored in interaction), thermal (TBD), chemical, nuclear…
- Energy may move back-and-forth between the various forms, but doesn't disappear or suddenly appears out of nowhere.
- An isolated system is a physical system that neither exchanges matter nor energy with its surroundings.
- In isolated systems, the total energy is conserved.
- So the total energy of an isolated system doesn't change with time
  - BUT: energy can move between different parts, and take different forms

Energy and Thermodynamics

- In thermodynamics, we are concerned with the microscopic kinetic and potential energy of atoms and molecules that make up a system



- Microscopic level:

  what happens to the atoms and molecules the object consists of?

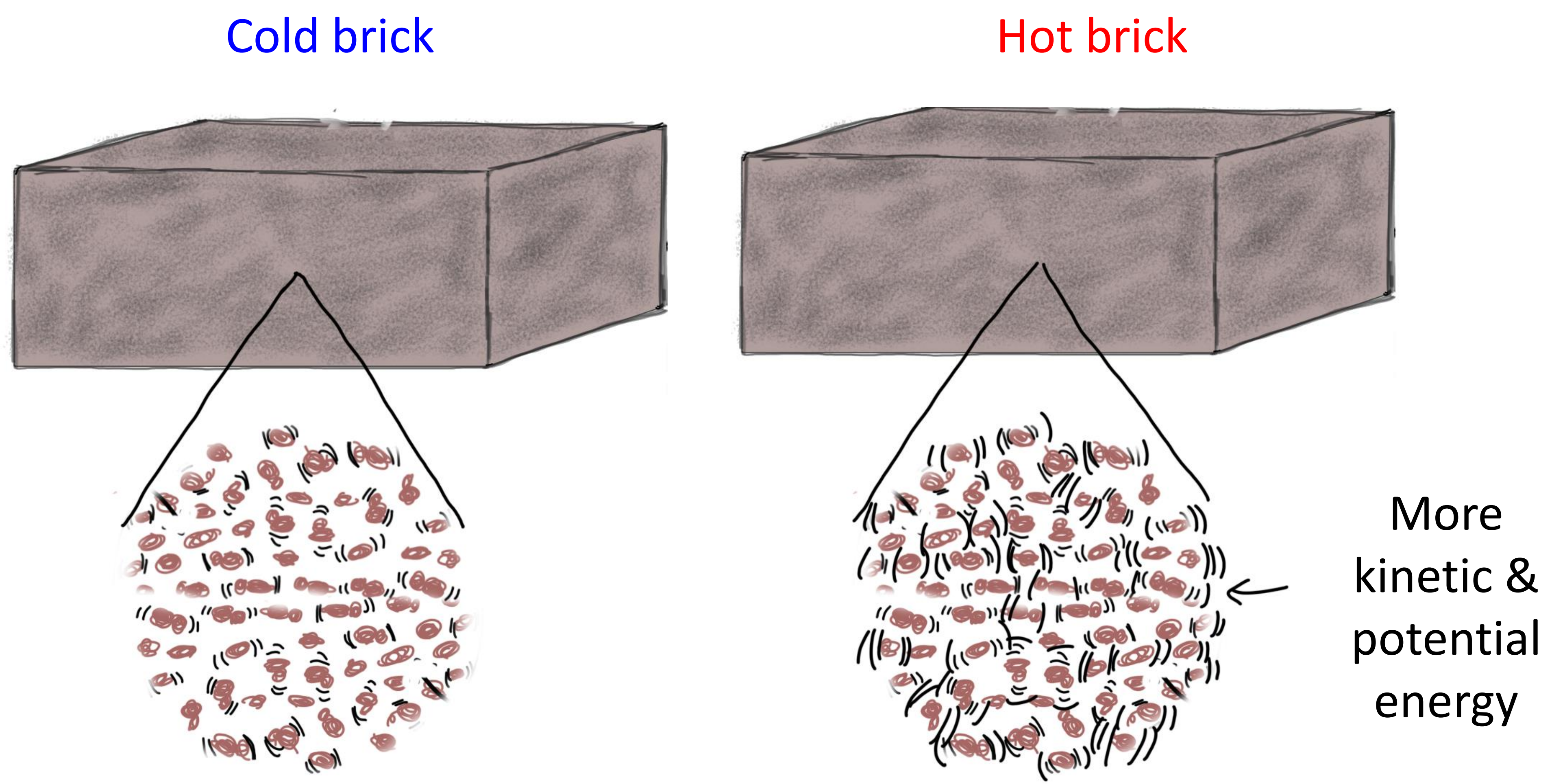
  molecule : k, u

Micro ⇔ Macro!

- Macroscopic object with macroscopic properties

  T; size.....

When we heat/cool an object, we are adding/removing energy at the molecular level:



Temperature (Macro)

- Informally, temperature is a measure for how “hot” or “cold” an object is (macro)
- The hotter an object, the more kinetic and potential energy is stored in its atoms and molecules (micro)
- A change in the temperature is accompanied by the change of other properties of an object (often slight changes), such as size and volume, radiation emitted, electric conductivity, ...
- Next week we will use those secondary changes to measure temperature (= express it with a number)

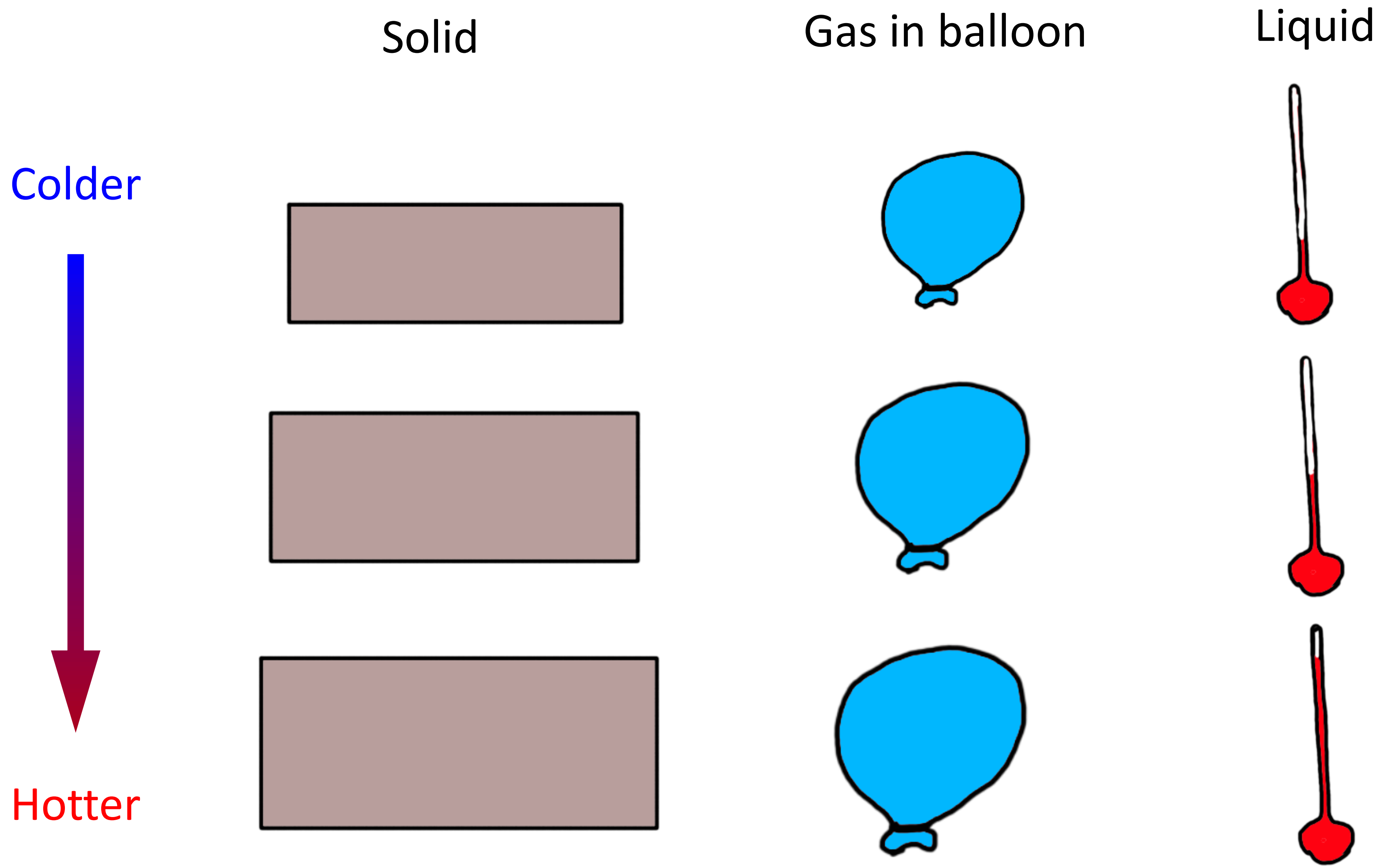
Q: Which microscopic properties of an object change when they are heated or cooled?

- Kinetic and potential energy of its atoms and molecules

Q: Which macroscopic properties of an object change when they are heated or cooled?

- Temperature!   …What else?
- Practically anything else! (but often only slightly)
  - Size, volume, density   mass = const!
  - Electrical conductivity, buoyancy, phases of matter, solubility…….
  - Amount of light / IR radiation emitted at different frequencies; color

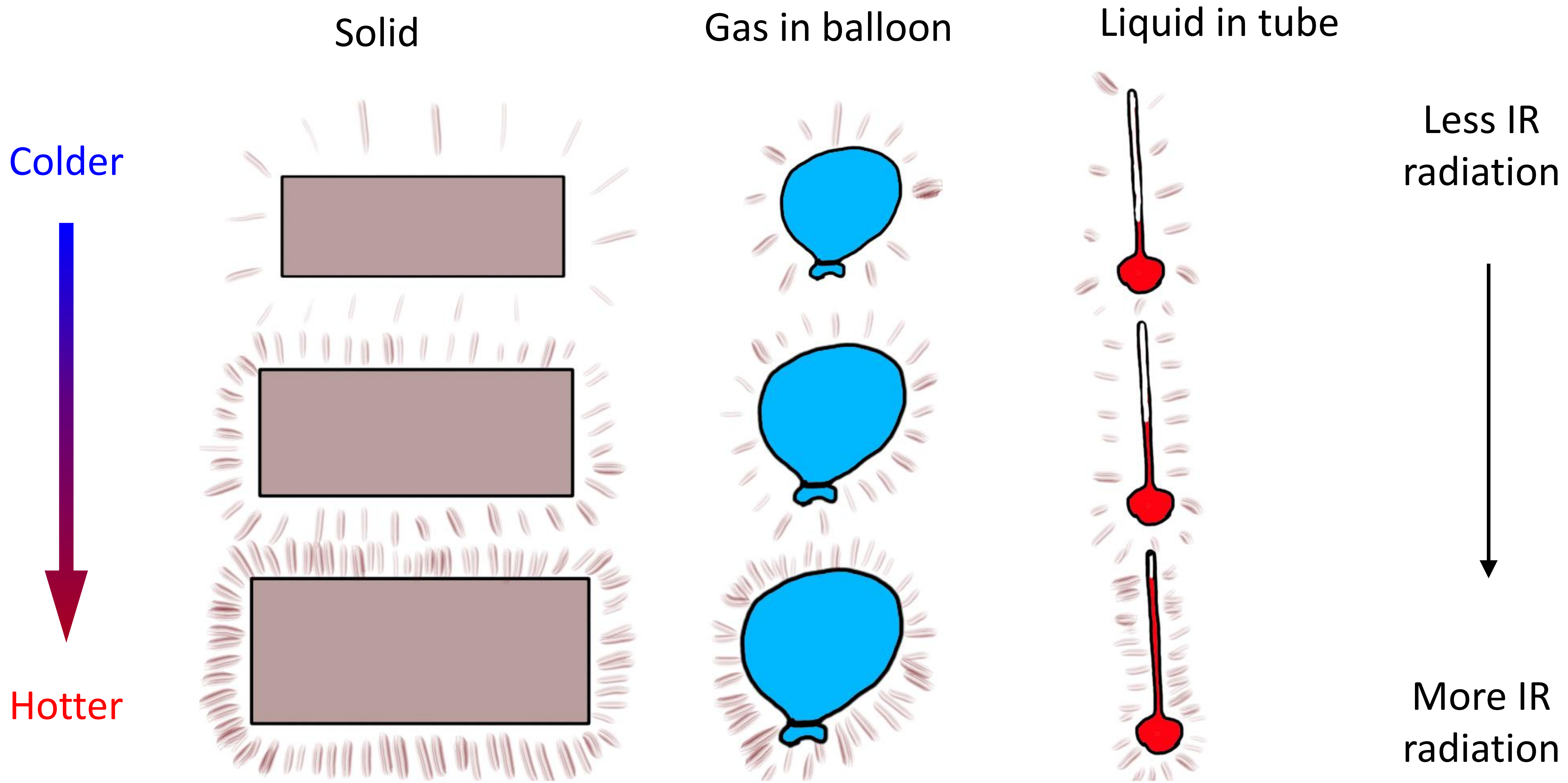
Examples: change in macroscopic properties



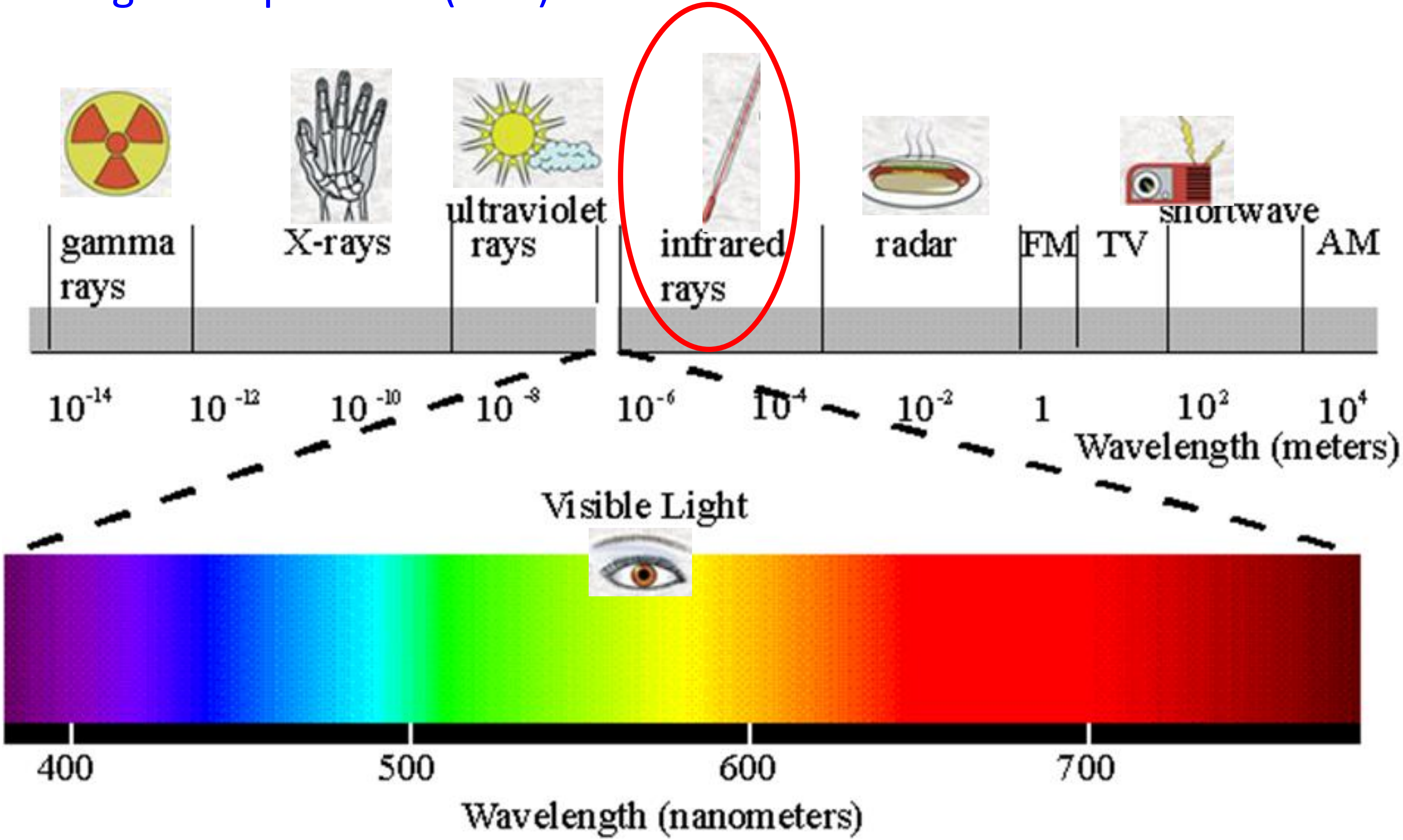
This is typical behavior, but there are exceptions!

(Size changes greatly exaggerated)

Examples: change in macroscopic properties



Electromagnetic spectrum (TBD)

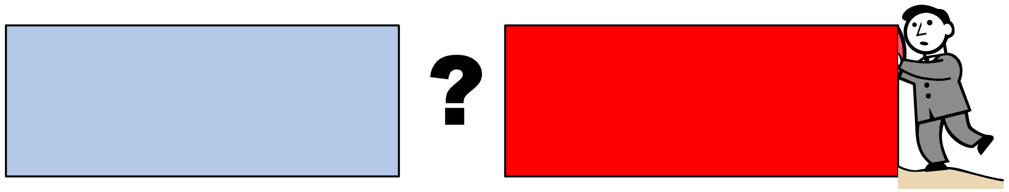


Summary

- Temperature is a measure of how much energy is stored in atoms and molecules of an object (micro)
- Many physical parameters of the object are linked to its temperature (macro)
- Now we will discuss how temperature (= energy of molecules) is transferred.

Hot block + room temperature block

Q: What happens if we put a hot block in contact with a room temperature block?



- Make a sketch of what you think we will see on IR camera. Use shades to show regions of different brightness.

  a) Just as we bring the blocks together

  b) After a short amount of time

  c) After a long amount of time

Demo: IR camera

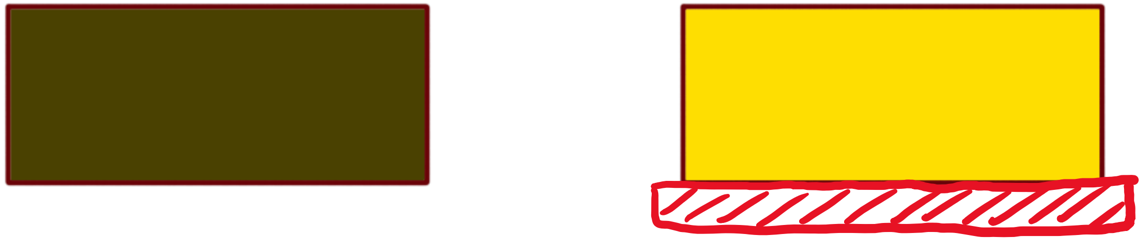
Make a prediction:

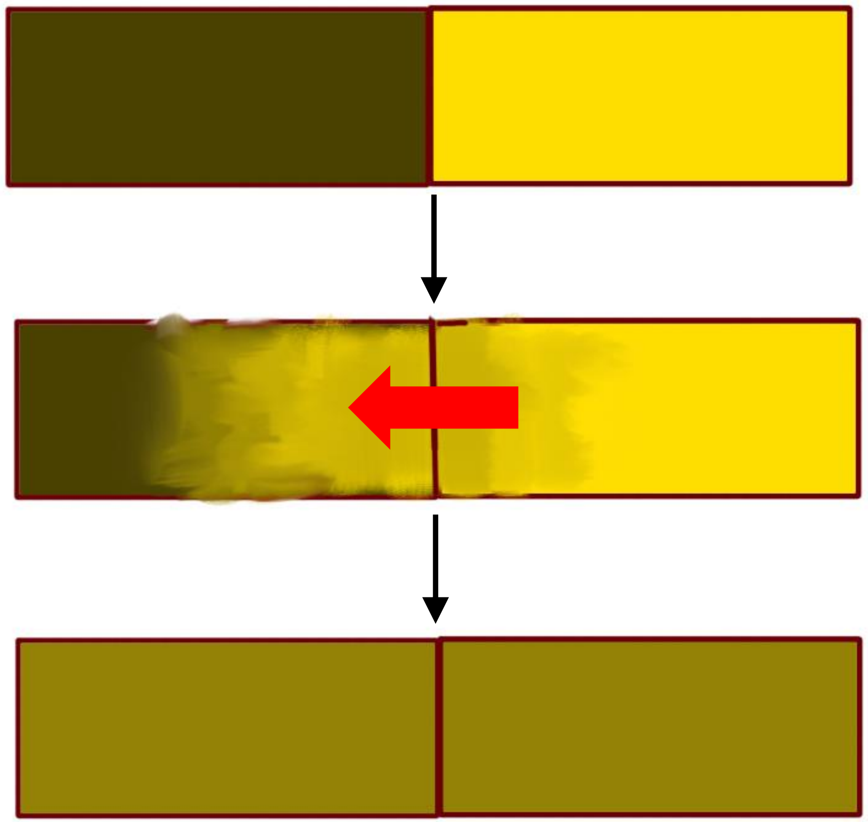
- We put together two blocks of aluminum, one heated on the hot plate and the other left in the room for a long time.
- We observe this on an infrared (IR) camera, which shows hotter objects as brighter.
- Make a sketch of what you think we will see
    a) Just as we bring the blocks together
    b) After a short amount of time
    c) After a long amount of time

(use shades to show regions of different brightness on the IR camera)

$T = 20°C$ $T = 270°C$

In equilibrium with room In equilibrium with hot plate





Place them in thermal contact

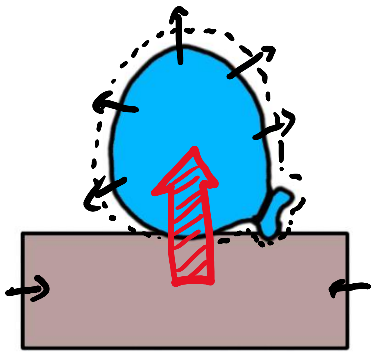
Heat flows

Blocks are not in equilibrium with each other, and each block is not in an equilibrium state (some parts are hotter)

Thermal equilibrium

Blocks are in equilibrium (same temperature & temperature is uniform)

If we bring two objects into contact, one of three things can happen:

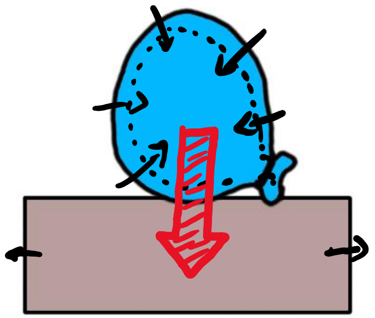


Energy flows from brick to balloon

=

flow of HEAT

Brick has higher temperature

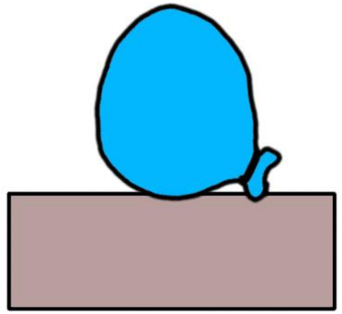


Energy flows from balloon to brick

=

flow of HEAT

Balloon has higher temperature



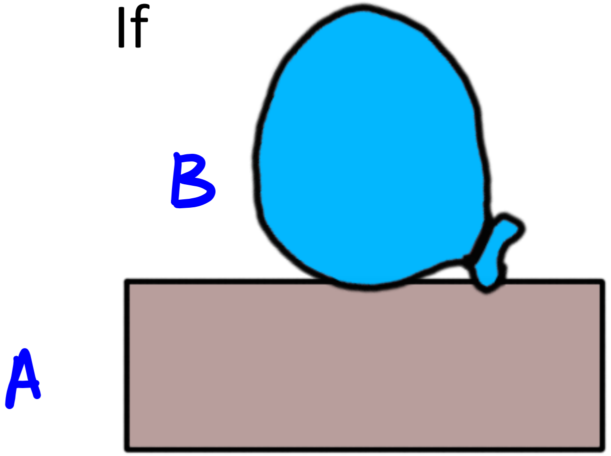
Nothing changes

We say the systems are in EQUILIBRIUM and AT SAME TEMPERATURE

- Two systems in thermal contact approach equilibrium
- In thermal equilibrium their temperatures are the same

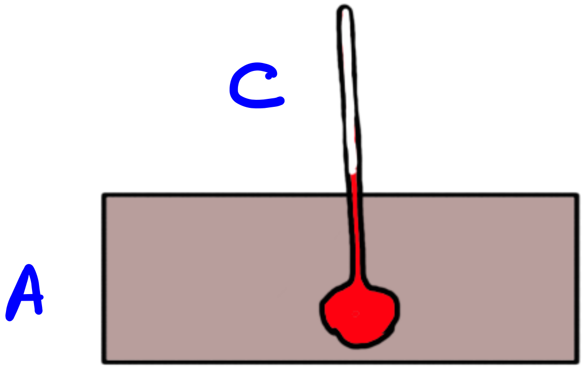
Zeroth Law of Thermodynamics

If



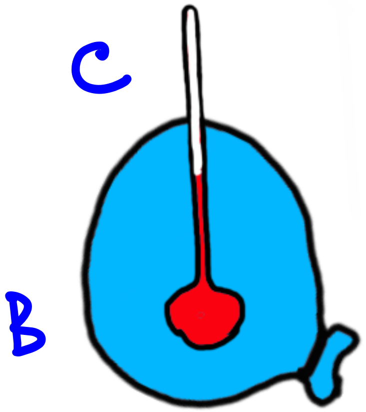
In equilibrium

and

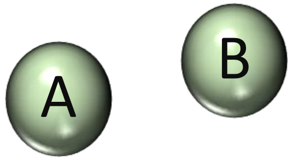


In equilibrium

then:

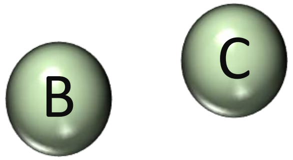


In equilibrium



same color

and



same color

What can you say about colors of A and C?

Q: A mercury thermometer sits in a glass of water.
If the thermometer reads 20^{o} C, we can conclude that:

A. The temperature of the water is 20^{o} C
B. The temperature of the mercury in the thermometer is 20^{o} C
C. Both A and B
D. Neither A nor B

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A. The temperature of the water is 20^{o} C
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C. Both A and B
D. Neither A nor B

The thermometer reading depends on the volume of the mercury, which is determined by its temperature. We are not told how long the thermometer has been in the water, so we don't know if it is in equilibrium with (and thus the same temp as) the water.

Q: Two objects (each initially in equilibrium) are put into thermal contact, and the pair is thermally insulated from its environment. If heat is observed to flow from object A to object B we can say that:

A. Object A initially had more energy than object B
B. Object A initially had a higher temperature than object B
C. Both A and B are true
D. Neither A nor B can be concluded from the question

Q: Two objects (each initially in equilibrium) are put into thermal contact, and the pair is thermally insulated from its environment. If heat is observed to flow from object A to object B we can say that:

A might be very small but hot

A. Object A initially had more energy than object B
B. Object A initially had a higher temperature than object B
C. Both A and B are true
D. Neither A nor B can be concluded from the question

This is one of the defining properties of temperature:

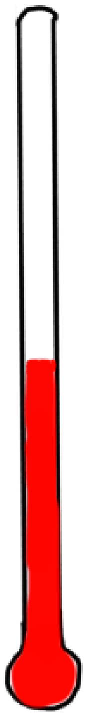
Temperature difference, ΔT, drives heat flow.

Extensive vs Intensive Properties

- Extensive properties depend on the amount of matter that is present
  - If the system is divided, the property is also divided between each part
  - Examples: mass, volume, energy, …

- Intensive properties do not depend on the amount of matter that is present
  - If the system is divided, the property is identical for each part
  - Examples: temperature, density, color, taste, melting/boiling point, …

- Next goal: Assign a value to the temperature!
- How?
- We can assign a numerical value for different temperatures by using some temperature dependent macroscopic property of a standard object (e.g., volume of liquid in a tube)



1 2 3 4 5 6 7 8 9 10

- Before next time, please do the reading assignment that is on Canvas

- Also do the reading quiz on Canvas that goes with it (due by Monday)