Announcements 24 Apr 09

- **Online homework grade**
  - Only 10 best scores are kept
- **Homework #11**
  - Written homework due at the start of class on Monday
  - Online homework due on Tuesday by 8 am
  - Problem 11.10:
    - Assume mass of the person = 68 kg
    - Power expended to ride a bicycle at a speed of 15 km/h = 480 J/s (i.e. 480 W)
    - 1 gram of gasoline corresponds to an energy of 44 kJ
- **Exam 3**
  - **Date change to Wednesday May 6** (7 to 9 pm)

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The Ideal Gas Model

The temperature of an ideal gas is a measure of the average kinetic energy of the atoms that make up the gas

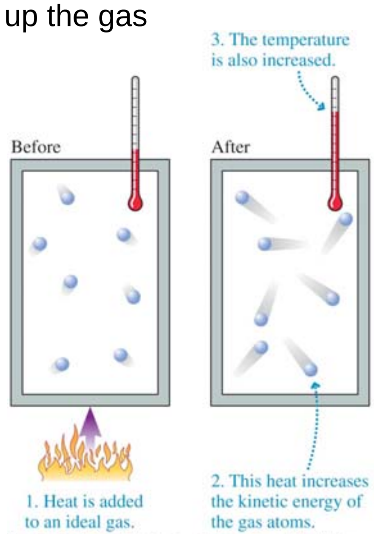
$$T = \frac{2}{3}\frac{K_{\text{avg}}}{k_{\text{B}}}$$

Typical (root mean square) speed of atoms in the gas

$$v_{\text{rms}} = \sqrt{\frac{3k_{\text{B}}T}{m}}$$

Thermal energy = total kinetic energy of N atoms

$$E_{\text{th}} = \frac{3}{2}Nk_{\text{B}}T$$



Boltzmann's constant: $k_B = 1.38 \times 10^{-23}$ J/K

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Temperature Scales

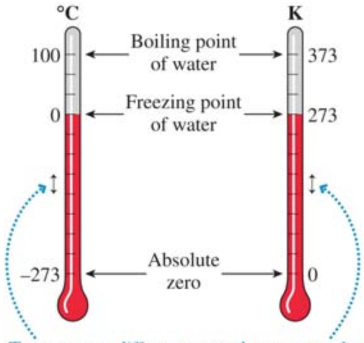
PRS

- Celsius scale (T_C)
  0 °C freezing point of pure water
  100 °C boiling point of pure water

- Fahrenheit scale (T_F)
  $$T_C = \frac{5}{9}\left(T_F - 32^\circ\right)$$

use Kelvin for E_{th} and temperature calculations

- Kelvin scale (T)
  0 K kinetic energy of atoms is zero
  $T = T_C + 273$



Temperature *differences* are the same on the Celsius and Kelvin scales. The temperature difference between the freezing point and boiling point of water is 100°C or 100 K.

Rank the following temperatures, from highest to lowest.

1. 300 °C
2. 300 K
3. 300 °F

A. 1 then 2 then 3
B. 1 then 3 then 2
C. 3 then 2 then 1

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PRS

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Rank the following temperatures, from highest to lowest.

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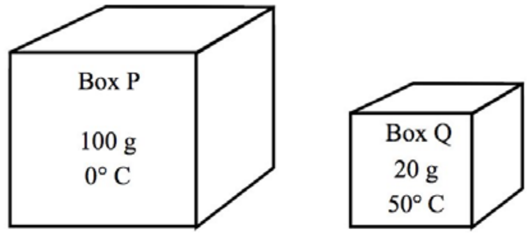
Thermal Energy Question

PRS

Two containers of the same gas (ideal) have these masses and temperatures:



- Which gas has atoms with the largest *average* thermal energy?
- Which container of gas has the largest thermal energy?

A. P, Q
B. P, P
C. Q, P
D. Q, Q

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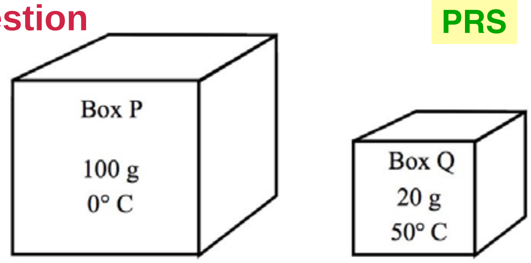
Thermal Energy Question

PRS

Two containers of the same gas (ideal) have these masses and temperatures:



- Largest *average* thermal energy corresponds to largest temperature, i.e. container Q
- Largest thermal energy corresponds to largest *total* thermal energy, i.e. container P

$$\text{Box P}: \; E_{th} = \frac{3}{2} N_P k_B T_P \quad = \frac{3}{2}(5N_Q) k_B (273+0)K$$

$$\text{Box Q}: \; E_{th} = \frac{3}{2} N_Q k_B T_Q \quad = \frac{3}{2} N_Q k_B (273+50)K$$

$$\frac{(E_{th})_P}{(E_{th})_Q} = \frac{(5N_Q)(273K)}{N_Q(323K)} = 4.34$$

use Kelvin scale for E_{th} and temperature calculations

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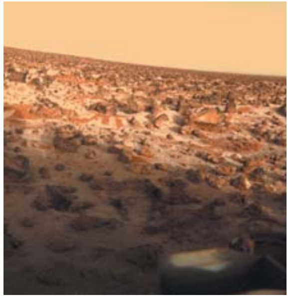
Ideal Gas Speeds

What are the rms speeds of a nitrogen molecule (mass 4.5 x 10^{-26} kg) at the following temperatures?

A. Room temperature: 68 °F (20 °C)
B. Coldest temperature on earth: –129 °F (–89 °C)
C. Polar night on Mars: –133 °C
D. Coldest laboratory temperature: 0.5 nK



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Ideal Gas Speeds

What are the rms speeds of a nitrogen molecule (mass 4.5 x 10^{-26} kg) at the following temperatures?

$$v_{\text{rms}} = \sqrt{\frac{3k_B T}{m}}$$

A. Room temperature: 68 °F (20 °C)
B. Coldest temperature on earth: –129 °F (–89 °C)
C. Polar night on Mars: –133 °C
D. Coldest laboratory temperature: 0.5 nK

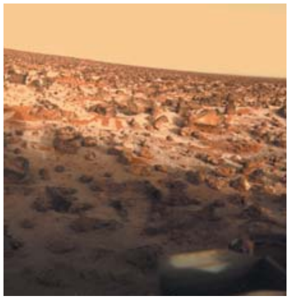
use Kelvin scale for E_{th} and temperature calculations

$$\text{A}: \; T = 273 + T_C = 273 + 20 = 293K$$

$$v_{rms} = \sqrt{\frac{3(1.38\times10^{-23} J/K)(293K)}{4.5\times10^{-26} kg}} = 510 m/s$$

$$\text{C}: \; T = 273 + T_C = 273 - 133 = 140K$$

$$v_{rms} = \sqrt{\frac{3(1.38\times10^{-23} J/K)(140K)}{4.5\times10^{-26} kg}} = 359 m/s$$



$$\text{D}: \; v_{rms} = \sqrt{\frac{3(1.38\times10^{-23} J/K)(0.5\times10^{-9} K)}{4.5\times10^{-26} kg}} = 6.8\times10^{-4} m/s$$

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Warming the Dorm

A college student is working on her physics homework in her 98 square foot dorm room with an 8 ft ceiling height. Her room contains a total of 6.0 x 10^{26} gas molecules. As she works, her body is converting chemical energy into thermal energy at a rate of 125 W. Her body stays at the same temperature, so all of this thermal energy must end up in the air of her room.

How much does this increase the temperature of the air in her room in 10 minutes of studying? Assume that her room is an isolated system (dorm rooms can certainly feel like that) filled with an ideal gas.

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Warming the Dorm

Find the temperature rise in the room

Know	Find
$N = 6.0 \times 10^{26}$	$\Delta T = ?$
$P = 125$ Watt	
$\Delta t = 10\,\text{min}$	

Body loses energy to the environment at rate given by P

$$\text{Power } P = \frac{energy}{time}$$

$$\Delta E_{th} = P \times \Delta t = (125W) \times \left(10\,\text{min} \times \frac{60s}{1\,\text{min}}\right) = 75kJ$$

$$\Delta E_{th} = \frac{3}{2} N k_B \Delta T$$

$$\Rightarrow \Delta T = \frac{\Delta E_{th}}{\frac{3}{2} N k_B} = \frac{75000J}{1.5\left(6.0 \times 10^{26}\right)\left(1.38 \times 10^{-23}\, J/K\right)} = 6.0K$$

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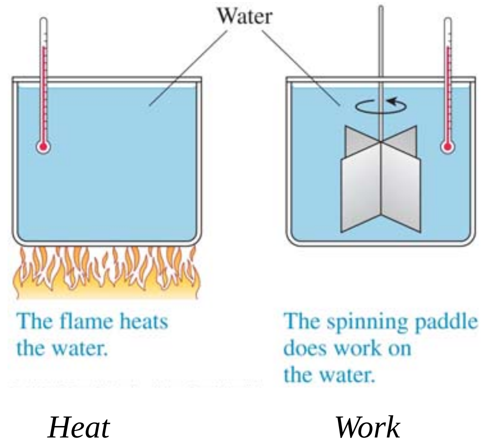
Heat

Heat is the energy transfer during a thermal interaction

Heat and work are two different ways of transferring energy to and from a system



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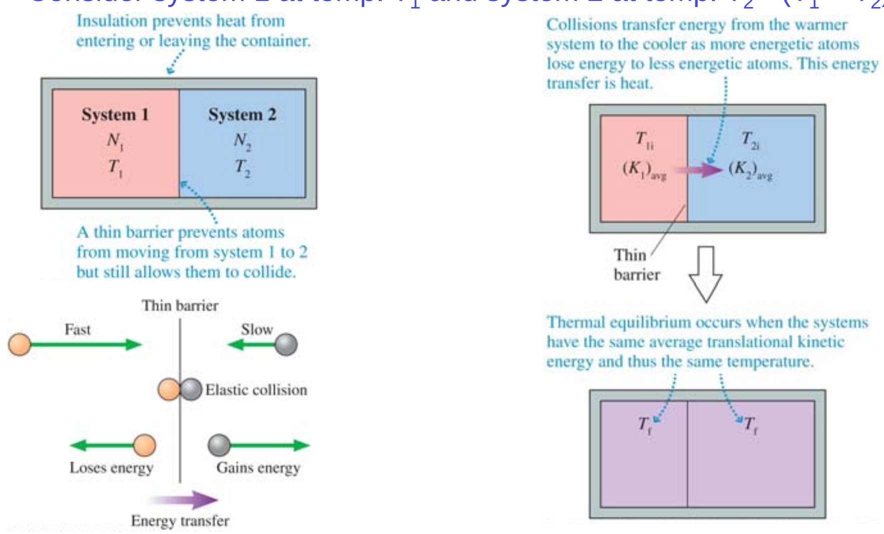
Atomic Model of Heat

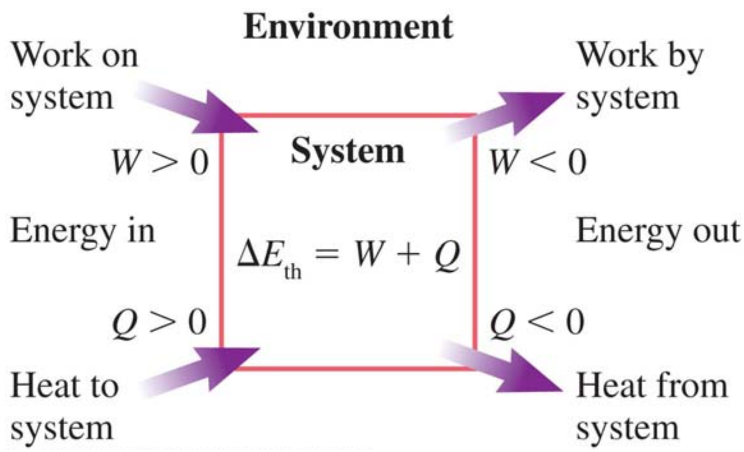
Consider system 1 at temp. T_1 and system 2 at temp. T_2 ($T_1 > T_2$)



Heat is energy transfer during thermal interaction between the two systems; energy transfer stops at thermal equilibrium ($T_1 = T_2$) 78

First law of thermodynamics For systems in which only the thermal energy changes, the change in thermal energy is equal to the energy transferred into or out of the system as work W and/or heat Q:

$$\Delta E_{th} = W + Q \qquad (11.14)$$



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Energy Transfer Question

PRS

Consider your body as a system. Your body is "burning" energy in food, but staying at a constant temperature. This means that, for your body,

A. $Q > 0$.

B. $Q = 0$.

C. $Q < 0$.

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