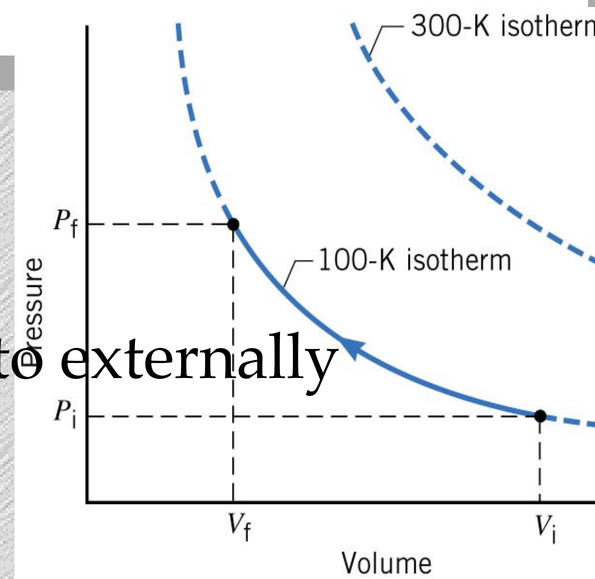
Laws of Thermodynamics

- Gas Laws
  - Kinetic Theory
  - Problems
- **The Laws**
  - Overview
  - Utility

$P\,V = n\,k\,T$ Gas Laws

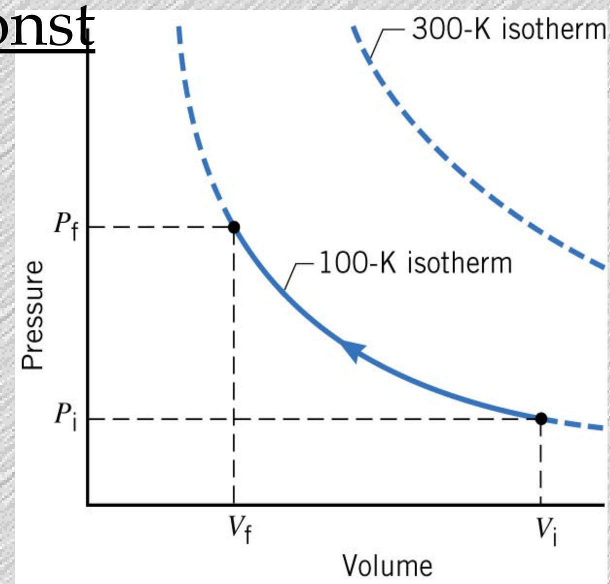


- Ideal Gas Law
  - Relates internal energy to externally measurable values.
  - For Any Given **T** , <u>P V = const</u>
  - P V is a measure of internal energy

$$k = 1.38 \cdot 10^{-23}\ {}^{J}\!/_{^\circ K}$$

$P\,V = n\,k\,T$ Gas Laws

- For Any Given **T** , <u>P V = const</u>



$$P\,V = Const, \qquad P_i\,V_i = P_f\,V_f$$

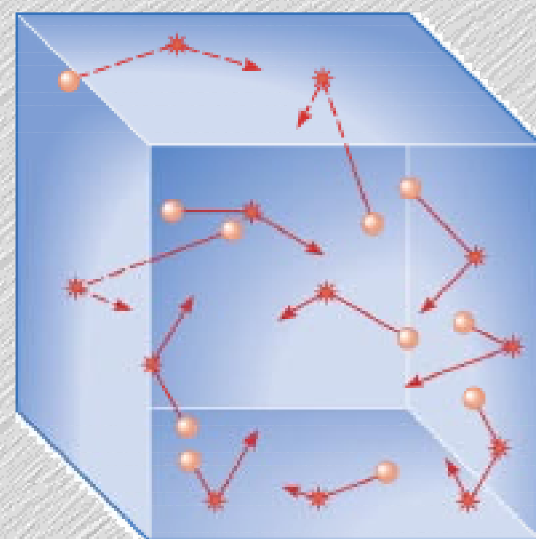
$$P = Const, \qquad \frac{V_i}{T_i} = \frac{V_f}{T_f}$$

- P V is a measure of internal energy

$$k = 1.38 \cdot 10^{-23}\ {}^{J}\!/_{\circ K}$$

P V as a measure of Int. Energy

- Consider the average force from a particle bouncing about a room.
- $P\,V = \frac{2}{3} N(\overline{KE})$

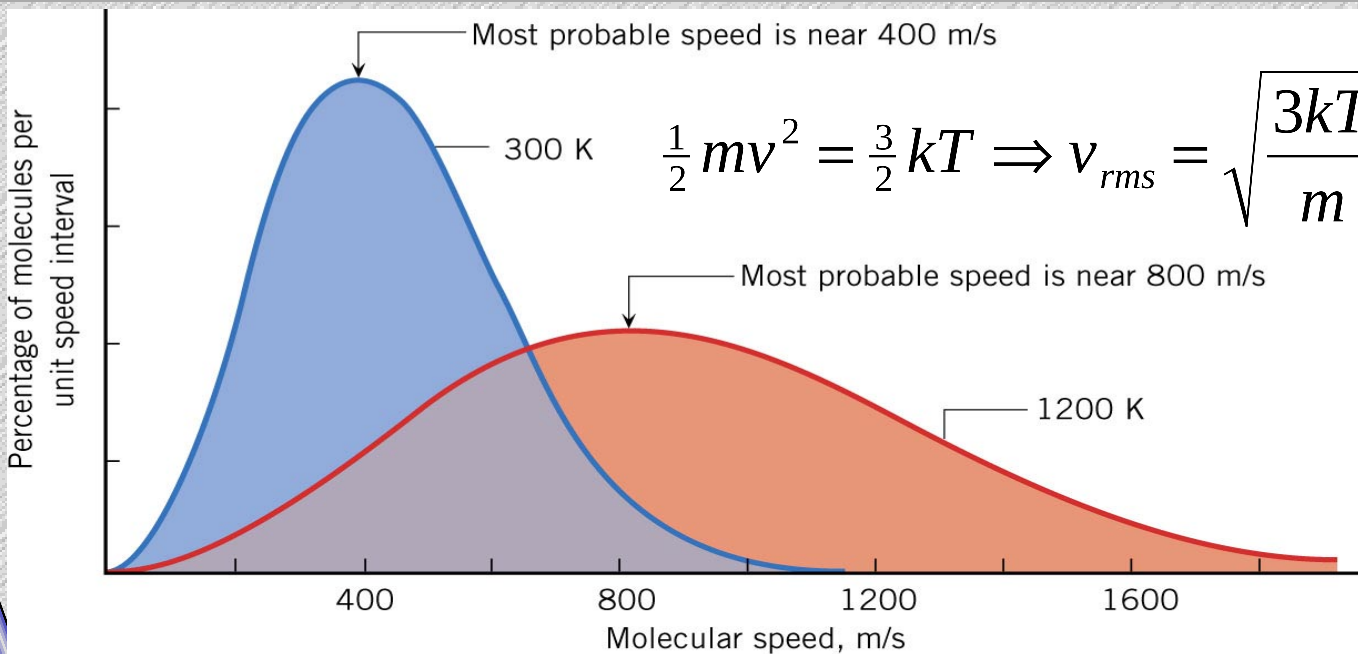


$$(\overline{KE}) = \frac{P\,V}{\frac{2}{3}N}, \quad \frac{1atm \cdot .0224m^3}{\frac{2}{3}N_A} = 5.7 \cdot 10^{-21} J$$

$$\frac{5.7 \cdot 10^{-21} J}{k(272°K)} = \frac{3}{2}, \quad 273°K = 0°C$$

$$\overline{KE} = \frac{1}{2} mv^2 = \frac{3}{2} kT$$

Distribution of Speeds



$$\tfrac{1}{2}mv^2 = \tfrac{3}{2}kT \Rightarrow v_{rms} = \sqrt{\frac{3kT}{m}}$$

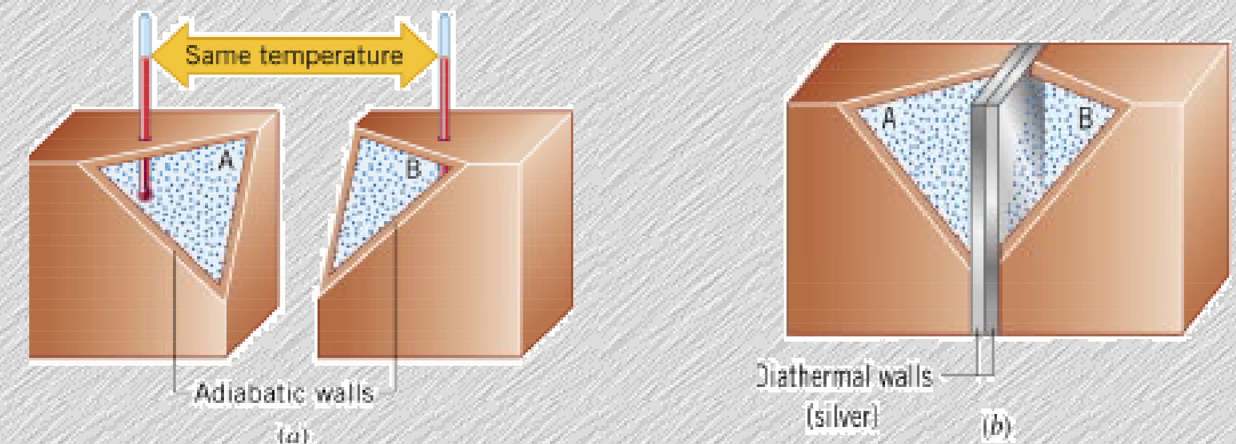
$$\sqrt{\frac{3kT}{m}} = \sqrt{\frac{3k\ 300°K}{29amu}} = 508\,{}^{m}\!/_{s} = 1136\,mph$$

Laws of Thermodynamics

- Zeroth Law

You are in a game!

  - *Temp is a valid measure of internal energy when the system is in equilibrium*

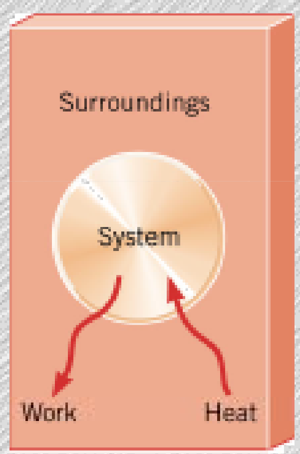


Laws of Thermodynamics

- First Law

You can't win the game!

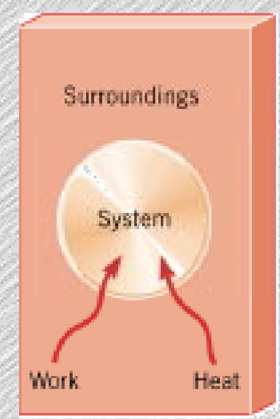
  - *Internal energy is the sum of heat and work done on it!*



$$\Delta U = Q + W$$

Note that this is different in expression from most textbooks but is the same idea.

Work is that which is done ON the system.



Laws of Thermodynamics

- First Law

You can't win the game!

- *Heat an ideal gas:* *1 mole of gas experiences a temperature decrease of 40°K while being heated. In one case the heat is 5500J and in the other only 1500J*
- **How can this happen?**
  - **The gas does work.** $\Delta U - Q = W$

$$\Delta U = \frac{3}{2} n\, k\, \Delta T = -2370J$$

$$1)\ W = -2370J - 5500J = -7870J$$

$$2)\ W = -2370J - 1500J = -3870J$$

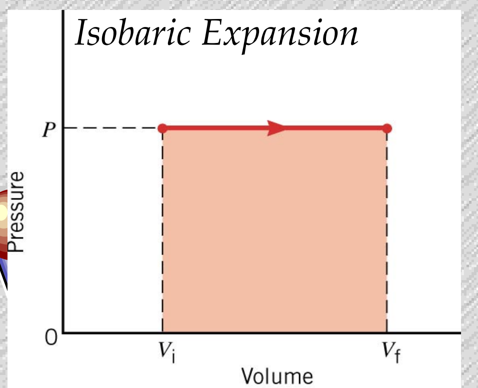
What does this mean? It means work flows out of the system. Internal energy is determined only by the # of mol and the temp. change.

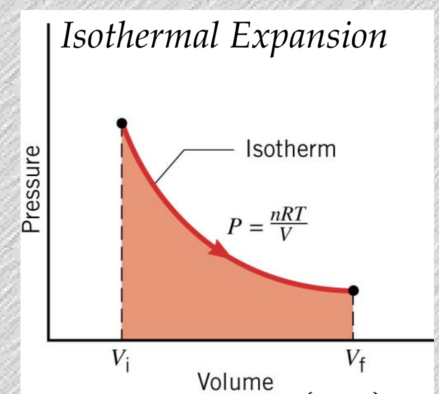
Laws of Thermodynamics

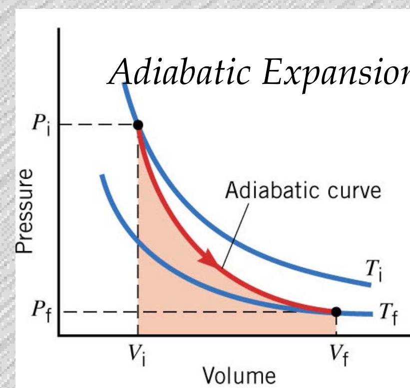
- First Law

You can't win the game!

- *Ways to get energy from a gas…*







$$W = P\,\Delta V$$

$$W = nRT\ln\left(\frac{V_f}{V_i}\right)$$

$$P_i V_i = P_f V_f$$

$$W = \tfrac{3}{2}nR(T_i - T_f)$$

$$P_i V_i^{\gamma} = P_f V_f^{\gamma}$$

$$\gamma = \tfrac{C_P}{C_V} = \tfrac{5}{3}$$

Physics

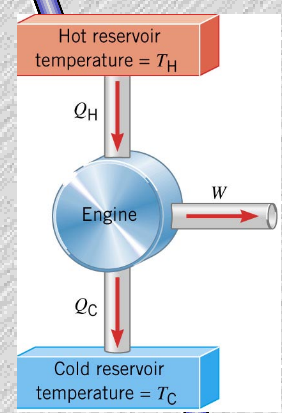
Paul Beeken

Laws of Thermodynamics

- Second Law

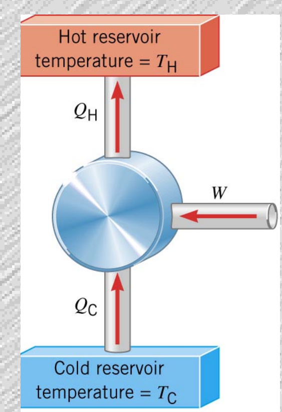
You can't break even!

- *Energy always naturally flows from Hot to Cold!*



$$efficiency = \frac{Work\ done}{Input\ heat} = \frac{W}{Q_H}$$

$$e = \frac{Q_H - Q_C}{Q_H} \qquad e = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H}$$



Laws of Thermodynamics

- Second Law — **You can't get out of the game!**

  - *What good is this waste heat?*
    - *Eventually this heat becomes useless because there is no temperature difference.*
    - *What happens to the % of heat not used in work?*
  - *Define a ratio of heat available to its temperature*

$$\Delta S = \left(\frac{Q}{T}\right)_R$$ **Entropy**