College Physics I: 1511 Mechanics & Thermodynamics

Professor Jasper Halekas
Van Allen Lecture Room 1
MWF 8:30-9:20 Lecture

Announcements

- Participation bonus credit has been assigned
  - Participation score out of 40 lectures
    - 35 classes with clicker questions +5 freebies for first two classes and lectures I was absent
    - +2 points to all to account for technological issues

  - 168 students ≥90% -> 2% bonus
  - 37 students <90% but ≥80% -> 1% bonus
  - 24 students <80% but ≥60% -> 0.5% bonus

Reminder: Course Evaluations

- Thank you all for being such a great class!
- Please fill out a course evaluation
  - Your constructive feedback is highly appreciated, will be taken very seriously, and will be used to improve future courses
- Completion rate at 19% as of 12/7/16
  - Deadline is Saturday night!

Heat, Ideal Gas, Thermo Equations

Heat:

$T_c = \frac{5}{9}(T_F - 32)$ $T_K = T_C + 273.15$ $\frac{\Delta L}{L} = \alpha \Delta T$ $\frac{\Delta V}{V} = 3\alpha \Delta T = \beta \Delta T$

$Q_{specific} = mc\Delta T$ $Q_{latent} = mL$ $\frac{Q_{conduction}}{t} = \frac{kA\,\Delta T}{L}$ $\frac{Q_{radiation}}{t} = e\sigma A T^4$

Ideal Gas:

$n = \frac{N}{N_A} = \frac{m}{M_{molar}}$ $PV = nRT = NkT$ $\langle KE \rangle = \frac{3}{2}kT$ $U_{monatomic} = \frac{3}{2}NkT = \frac{3}{2}nRT$

Thermodynamics:

$\Delta U = Q - W$

$W = P\Delta V = nR\Delta T$ *(isobaric, const. P)* $W = nRT\, ln(\frac{V_f}{V_i})$ *(isothermal, const. T)*

$W = -\frac{3}{2}nR(T_f - T_i)$ *(adiabatic, monatomic)* $P_1 V_1{}^{\gamma} = P_2 V_2{}^{\gamma}$ *(adiabatic)*

$Q = Cn\Delta T$ $C_{P\_monatomic} = \frac{5}{2}R$ $C_{V\_monatomic} = \frac{3}{2}R$ $\gamma = C_P/C_V$ *(= 5/3 for monatomic)*

$e = \frac{|W|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$ $|Q_H| = |W| + |Q_C|$ $\frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H}$ *(Carnot engine)*

$\Delta S = Q/T$ *(Reversible processes)*

Heat

Heat:

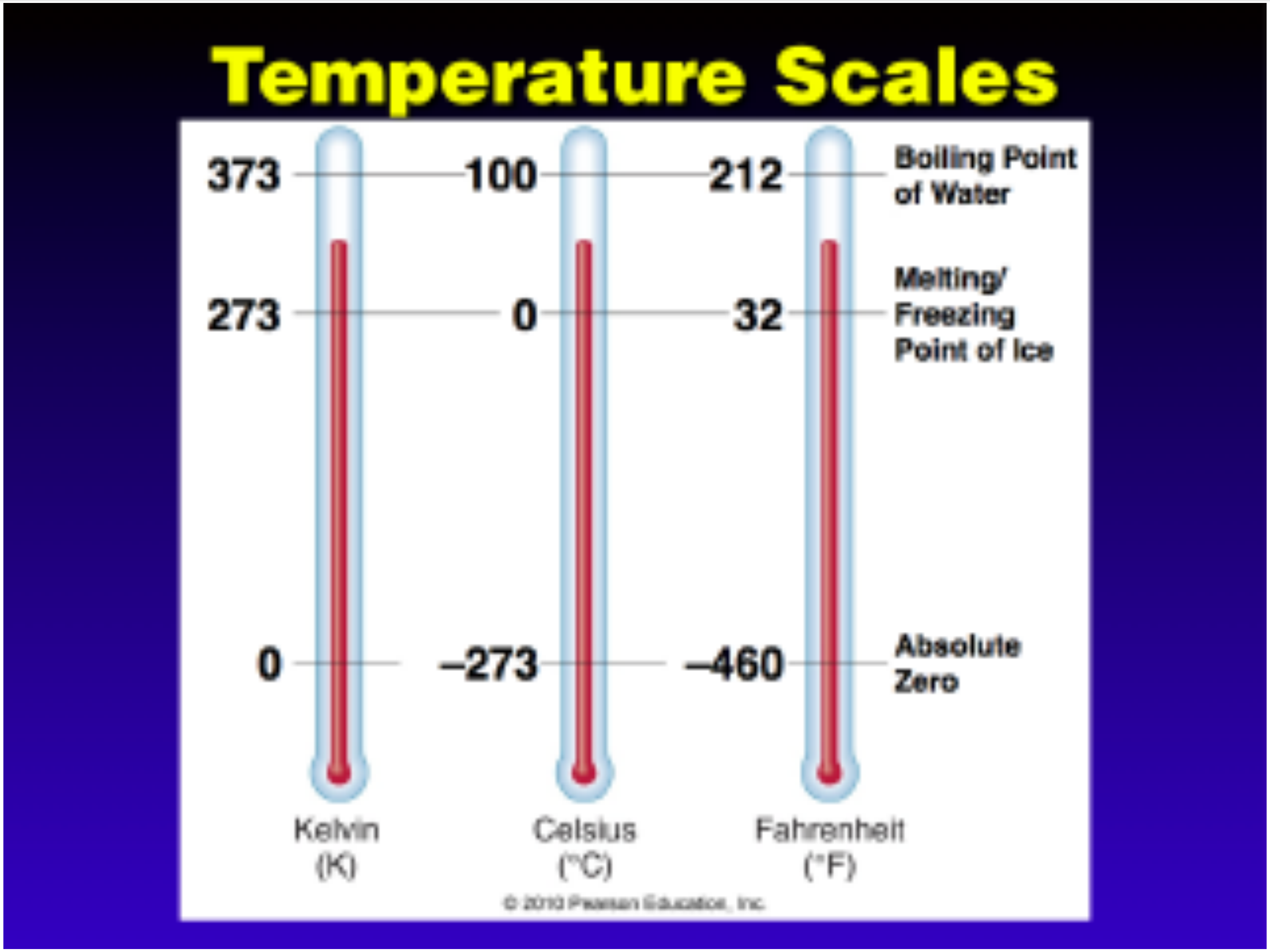
$$T_c = \frac{5}{9}(T_F - 32) \qquad T_K = T_C + 273.15$$

$$Q_{specific} = mc\Delta T \qquad Q_{latent} = mL$$

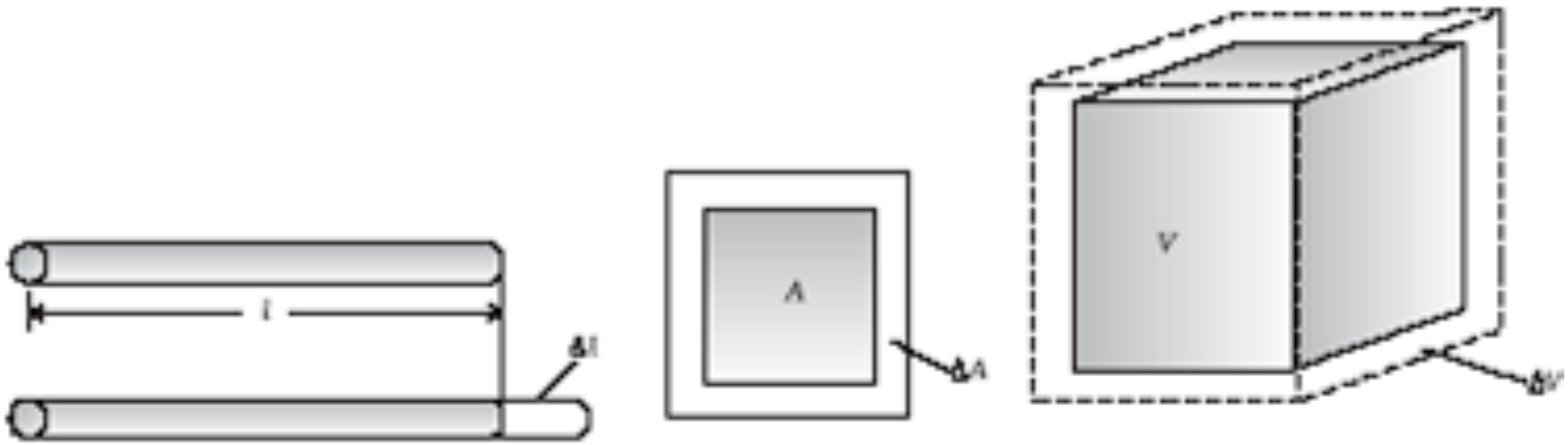
$$\frac{\Delta L}{L} = \alpha\Delta T \qquad \frac{\Delta V}{V} = 3\alpha\Delta T = \beta\Delta T$$

$$\frac{Q_{conduction}}{t} = \frac{kA\,\Delta T}{L} \qquad \frac{Q_{radiation}}{t} = e\sigma A T^4$$

Temperature Scales



Change in Dimension Due to Heat



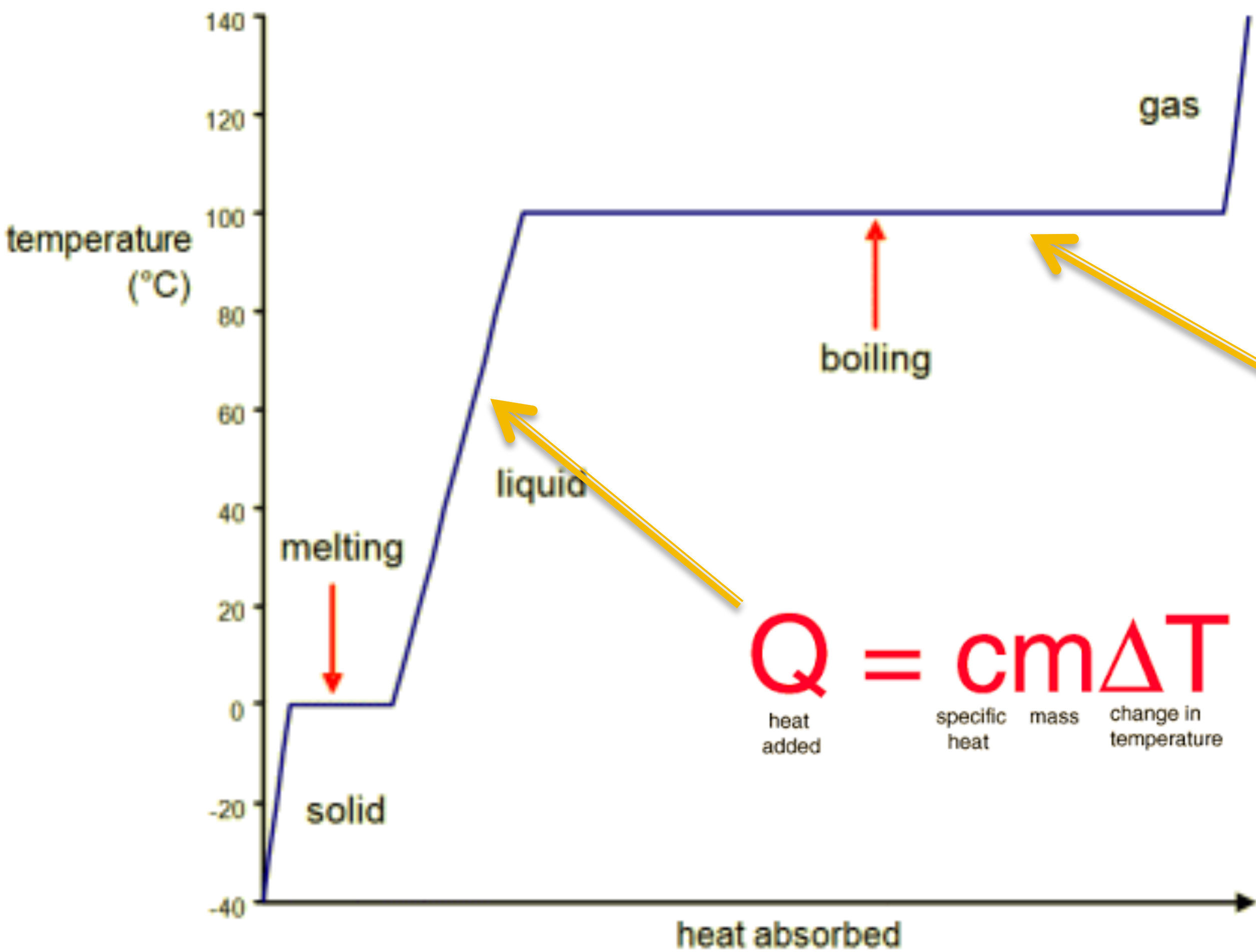
$$\frac{\Delta l}{l} = a_1 \Delta T$$

$$\frac{\Delta A}{A} = 2a_1 \Delta T$$

$$\frac{\Delta V}{V} = 3a_1 \Delta T = \beta \Delta T$$

(a) Linear expansion (b) Area expansion (c) Volume expansion

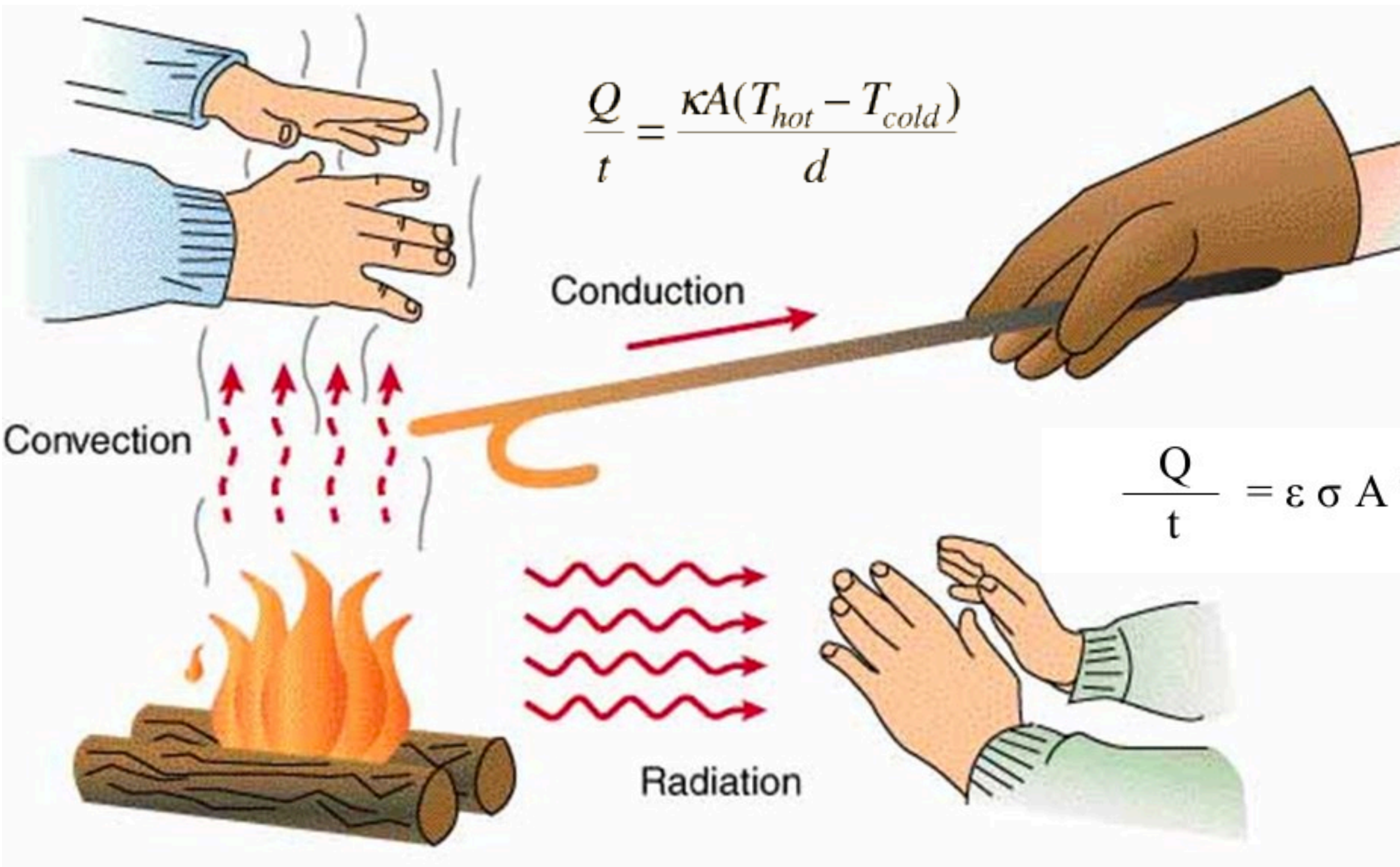
Specific & Latent Heat



$$Q = mL$$

Q = Heat Change	(J or Nm)
m = mass	(kg)
L = specific latent heat	(J kg^{-1})

Heat Transfer



$$\frac{Q}{t} = \frac{\kappa A(T_{hot} - T_{cold})}{d}$$

$$\frac{Q}{t} = \varepsilon \sigma A T^4$$

Practice Question

- A solid cube with an initial volume of 5 m^3 has a volume expansion coefficient $\beta = 10^{-5}/°C$. How much do you have to increase its temperature to increase its volume by 0.001 m^3 (one liter)?

A. 1 °C
B. 2 °C
C. 5 °C
D. 10 °C
E. 20 °C

$$\Delta V / V = \beta \Delta T$$

$$\frac{.001}{5} = .00001 \ \Delta T$$

$$\frac{100}{5} = \Delta T$$

$$\boxed{20 = \Delta T}$$

Practice Question

- A solid cube with an initial volume of 5 m^3 has a volume expansion coefficient $\beta = 10^{-5}/°C$. How much do you have to increase its temperature to increase its volume by 0.001 m^3 (one liter)?

A. 1 °C
B. 2 °C
C. 5 °C
D. 10 °C
E. 20 °C

Practice Question

- A 4 kg sample of ice at 0.0 °C falls through a distance of 30.0 m and undergoes a completely inelastic collision with the earth. If all of the mechanical energy is absorbed by the ice, how much of it melts? Assume that $g = 10\ m/s^2$ and the latent heat of ice $L = 300\ J/g$.

A. 8 g
B. 3 g
C. 4 g
D. 20 g
E. 40 g

$$\Delta KE = Mgh$$
$$= 4 \cdot 10 \cdot 30$$
$$= 1200 \text{ J}$$

$$Q = mL$$
$$= m \cdot 300$$
$$= 1200$$
$$\Rightarrow m = 1200 / 300$$
$$= \boxed{4 \text{ g}}$$

Practice Question

- A 4 kg sample of ice at 0.0 °C falls through a distance of 30.0 m and undergoes a completely inelastic collision with the earth. If all of the mechanical energy is absorbed by the ice, how much of it melts? Assume that $g = 10\ m/s^2$ and the latent heat of ice $L = 300\ J/g$.

A. 8 g
B. 3 g
C. 4 g
D. 20 g
E. 40 g

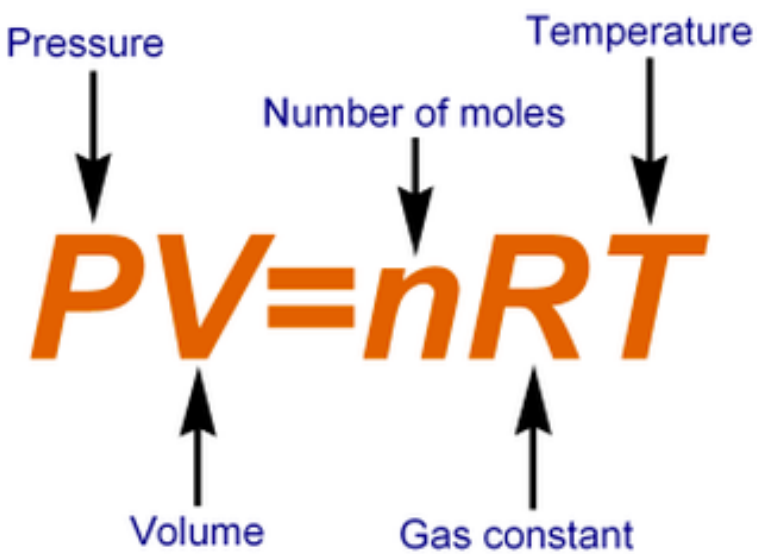
Ideal Gas

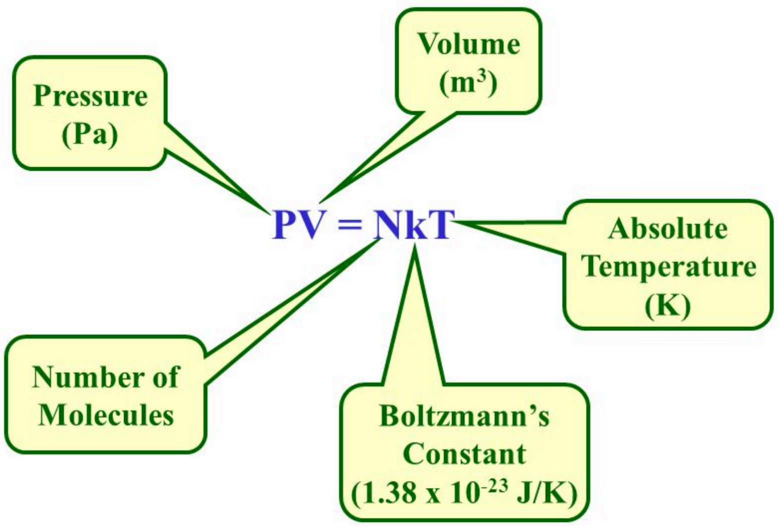
Ideal Gas:

$$n = \frac{N}{N_A} = \frac{m}{M_{molar}} \qquad PV = nRT = NkT$$

$$\langle KE \rangle = \frac{3}{2}kT \qquad U_{monatomic} = \frac{3}{2}NkT = \frac{3}{2}nRT$$

Ideal Gas Law





Internal Energy of Gas

For All Ideal Gases:

$$KE_{avg} = \left[\overline{\frac{1}{2}mv^2}\right] = \frac{3}{2}kT$$

For Monatomic Gas:

$$U = nN_A KE_{avg} = nN_A \frac{3}{2}kT = \frac{3}{2}nRT$$

Practice Question

- An ideal gas is initially at $T = 150$ K, $p = 2 \times 10^5$ Pa, and $V = 6\ cm^3$. The temperature is then increased to 300 K. Which of the following might be the pressure and volume of the final state?

A. $p = 1 \times 10^5$ Pa and $V = 6\ cm^3$
B. $p = 2 \times 10^5$ Pa and $V = 3\ cm^3$
C. $p = 3 \times 10^5$ Pa and $V = 9\ cm^3$
D. $p = 3 \times 10^5$ Pa and $V = 8\ cm^3$
E. $p = 4 \times 10^5$ Pa and $V = 12\ cm^3$

$$P_0 V_0 = nRT_0$$
$$PV = nR \cdot 2T_0$$
$$= 2P_0V_0$$

only case that works is

$$\boxed{\begin{aligned} P &= 3 \times 10^5 \\ V &= 8 \text{ cm}^3 \end{aligned}}$$

Practice Question

- An ideal gas is initially at $T = 150$ K, $p = 2 \times 10^5$ Pa, and $V = 6\ cm^3$. The temperature is then increased to 300 K. Which of the following might be the pressure and volume of the final state?

A. $p = 1 \times 10^5$ Pa and $V = 6\ cm^3$
B. $p = 2 \times 10^5$ Pa and $V = 3\ cm^3$
C. $p = 3 \times 10^5$ Pa and $V = 9\ cm^3$
D. $p = 3 \times 10^5$ Pa and $V = 8\ cm^3$
E. $p = 4 \times 10^5$ Pa and $V = 12\ cm^3$

Thermodynamics

Thermodynamics:

$\Delta U = Q - W$

$W = P\Delta V = nR\Delta T$ *(isobaric, const. P)* $W = nRT\, ln(\frac{V_f}{V_i})$ *(isothermal, const. T)*

$W = -\frac{3}{2}nR(T_f - T_i)$ *(adiabatic, monatomic)* $P_1{V_1}^{\gamma} = P_2{V_2}^{\gamma}$ *(adiabatic)*

$Q = Cn\Delta T$ $C_{P\_monatomic} = \frac{5}{2}R$ $C_{V\_monatomic} = \frac{3}{2}R$ $\gamma = C_P/C_V$ *(= 5/3 for monatomic)*

$e = \frac{|W|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$ $|Q_H| = |W| + |Q_C|$ $\frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H}$ *(Carnot engine)*

$\Delta S = Q/T$ *(Reversible processes)*

First Law

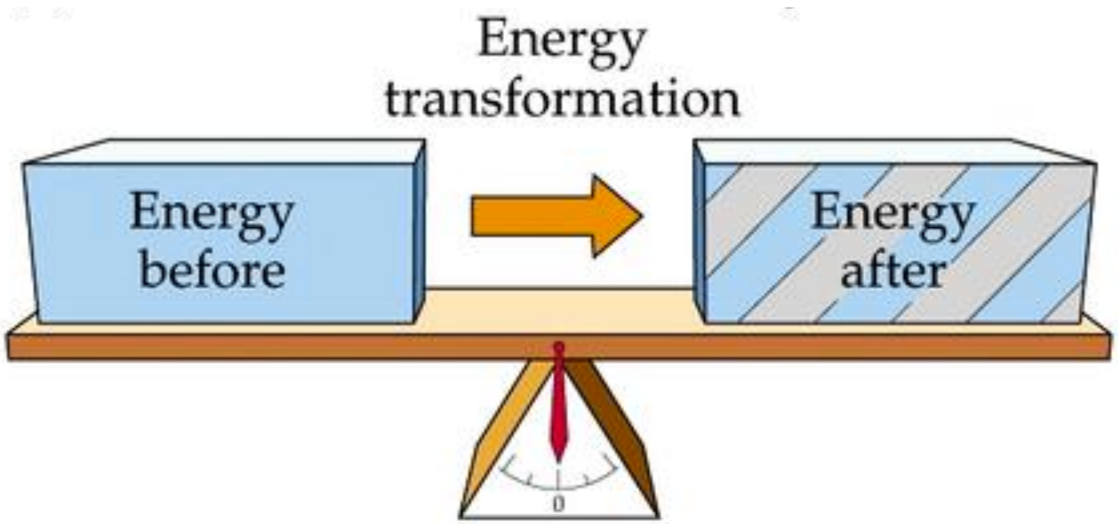
The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

$$\Delta U = Q - W$$

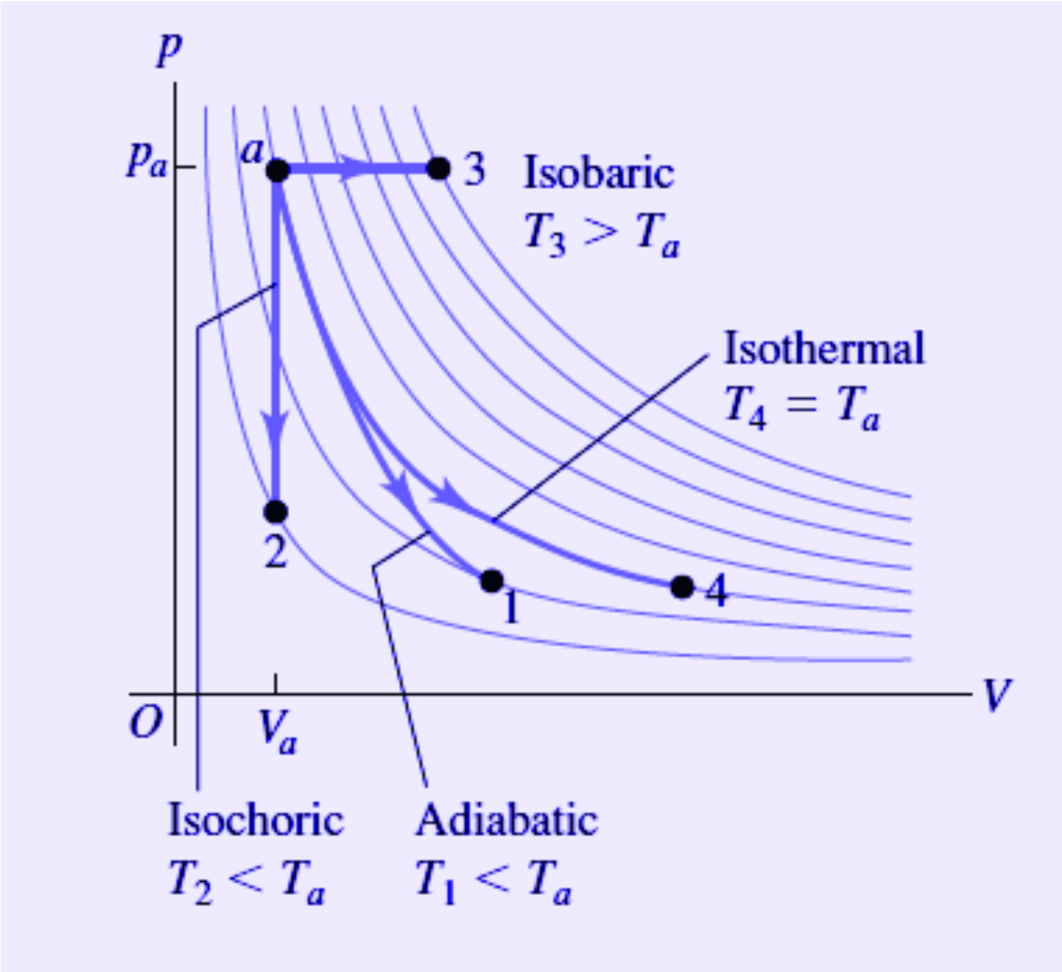
Change in internal energy

Heat added to the system

Work done by the system



Ideal Gas Processes

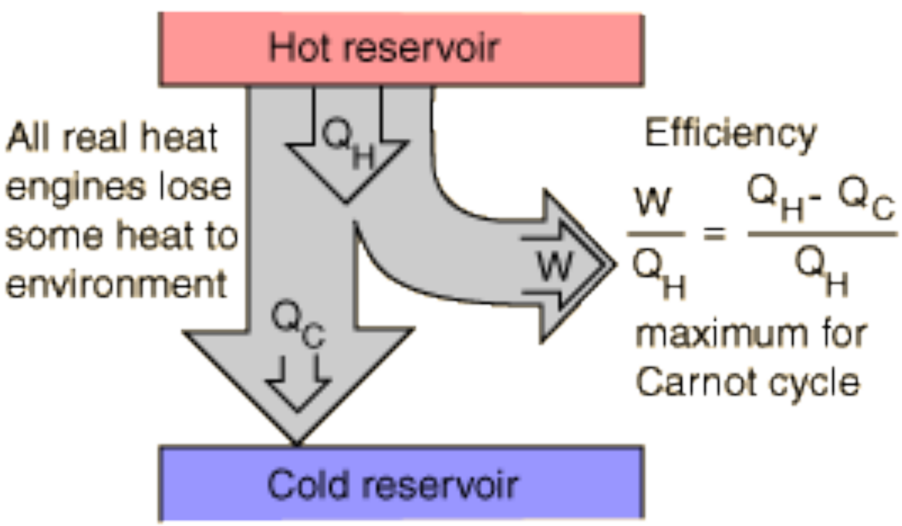


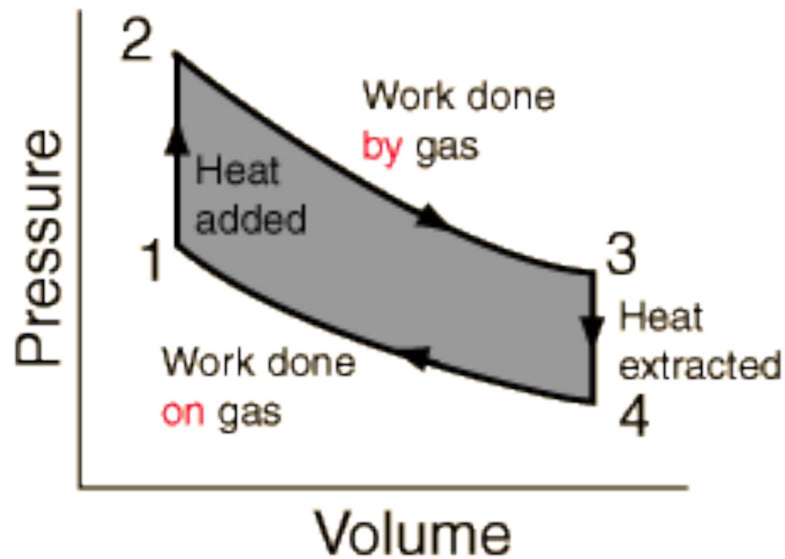
Work done by gas = area under curve

Ideal Gas Processes

Process	ΔU	Q	W
Constant Volume	$3/2\ nR\ \Delta T$ (monatomic)	$3/2\ nR\ \Delta T$ (monatomic)	0
Constant Pressure	$3/2\ nR\ \Delta T$ (monatomic)	$5/2\ nR\ \Delta T$ (monatomic)	$P\Delta V = nR\ \Delta T$
Constant Temperature	0	$nRT \ln (V_f/V_i)$	$nRT \ln (V_f/V_i)$
Adiabatic (pV^{γ} = constant)	$3/2\ nR\ \Delta T$ (monatomic)	0	$-3/2\ nR\ \Delta T$ (monatomic)

Heat Engines

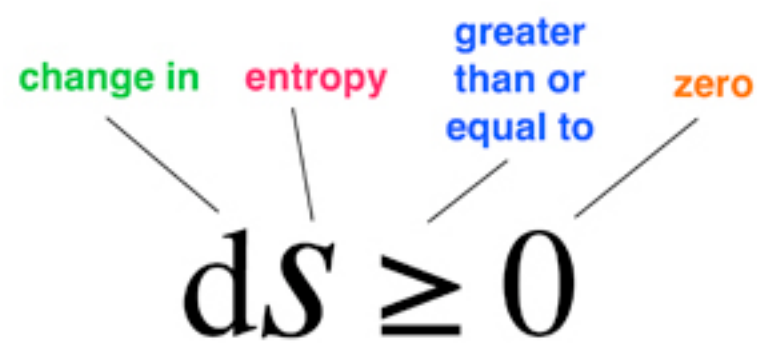




Second Law

- No perfect heat engines
- Can't reach absolute zero
- In an isolated system, heat always flows from hot to cold
- Entropy of an isolated system is constant or increasing

$\Delta S = Q/T$

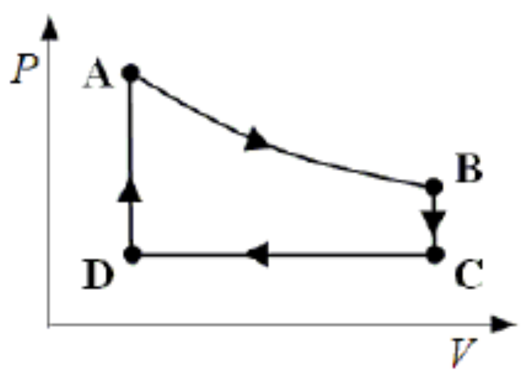


Practice Question

- An ideal monatomic gas expands isothermally from state **A** to state **B**. The gas then cools at constant volume to state **C**. The gas is then compressed isobarically to **D** before it is heated until it returns to state **A**.

- How much work is done on the gas as it is compressed isobarically from state **C** to state **D**? Assume atmospheric pressure = $1\text{x}10^5$ Pa, and one liter = $0.001\ m^3$.

A. 200 J
B. 400 J
C. zero J
D. 50 J
E. 100 J



$V_A = V_D = 2$ liters $V_B = V_C = 4$ liters
P_A 10 atm $T_A = 327\ °C$
$P_C = 2$ atm

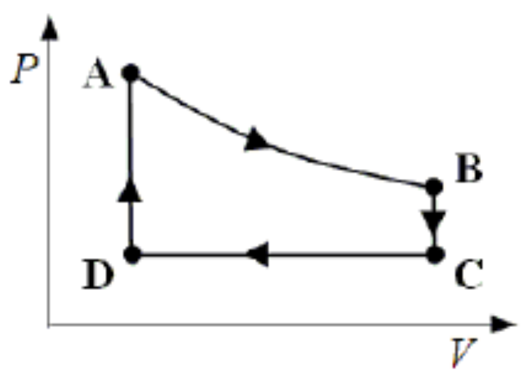
$$W = P\Delta V$$
$$= 2\times10^5\,(2\times0.001 - 4\times0.001)$$
$$= 2\times10^5 \cdot -2\times10^{-3}$$
$$= -400\,J \quad W_{by}$$
$$= \boxed{+400\,J \quad W_{on}}$$

Practice Question

- An ideal monatomic gas expands isothermally from state **A** to state **B**. The gas then cools at constant volume to state **C**. The gas is then compressed isobarically to **D** before it is heated until it returns to state **A**.

- How much work is done on the gas as it is compressed isobarically from state **C** to state **D**? Assume atmospheric pressure = 1×10^5 Pa, and one liter = 0.001 m^3.

A. 200 J
B. 400 J
C. zero J
D. 50 J
E. 100 J

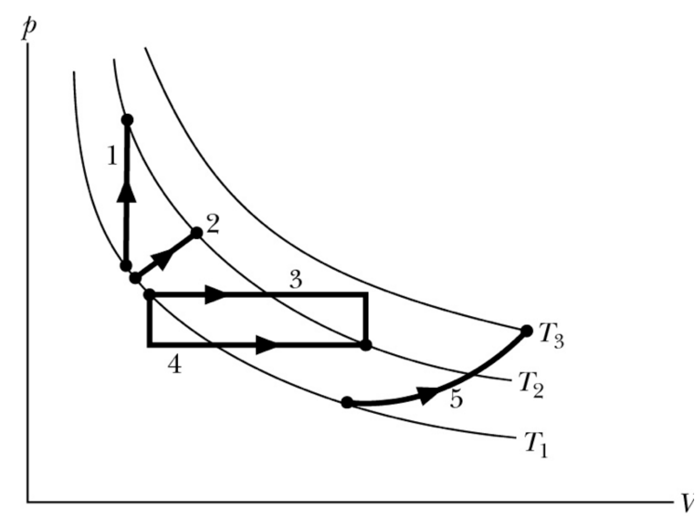


$V_A = V_D = 2$ liters $\quad V_B = V_C = 4$ liters
P_A 10 atm $\quad T_A = 327\,°C$
$P_C = 2$ atm

Practice Question

The figure below shows five paths traversed by a monatomic gas on a p-V diagram. Rank the paths according to the change in internal energy of the gas, greatest first.

1) all tie
2) 5, 12, 34
3) 34, 12, 5
4) 1234, 5
5) 5, 1234



$$\Delta U = \tfrac{3}{2} nR\Delta T$$

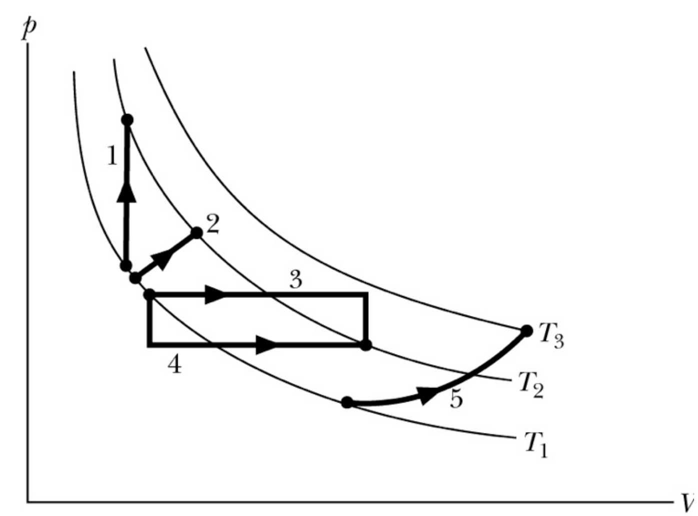
for monatomic

$$\boxed{\Delta T_5 > \Delta T_1 = \Delta T_2 = \Delta T_3 = \Delta T_4}$$

Practice Question

The figure below shows five paths traversed by a monatomic gas on a p-V diagram. Rank the paths according to the change in internal energy of the gas, greatest first.

1) all tie
2) 5, 12, 34
3) 34, 12, 5
4) 1234, 5
5) 5, 1234



Practice Question

- A certain heat engine draws 500 J/s from a water bath at 27°C and rejects 400 J/s to a reservoir at a lower temperature. The efficiency of this engine is:

A. 80%
B. 75%
C. 55%
D. 25%
E. 20%

$$e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$$

$$= \frac{500 - 400}{500}$$

$$= \frac{100}{500} = 0.2$$

$$= 20\%$$

Practice Question

- A certain heat engine draws 500 J/s from a water bath at 27°C and rejects 400 J/s to a reservoir at a lower temperature. The efficiency of this engine is:

A. 80%
B. 75%
C. 55%
D. 25%
E. 20%