Review of Some Ideas...

Specific Heats

\[ Q = cm \Delta T \]

Latent Heat

(Heat of Transformation)

\[ Q = mL \]

\[ L_V \quad \text{and} \quad L_P \]

\{ Changes of Phase \}

System of Interest...

\[ W \] by gas

\[ \frac{W}{P} \]

\[ V \]

\[ W_{gas} = \int_A^B PdV \]

1st Law of Thermodynamics

\[ \Delta Q = \Delta U + \Delta W \]

State Functions

\[ u, T, p, v \]

Internal energy characterized by temperature
PARTICULAR FOCUS

1) Isothermal processes, \( \Delta T = 0 \Rightarrow \Delta U = 0 \)
\[ \Delta Q = \Delta W \]

2) Adiabatic processes, \( \Delta Q = 0 \Rightarrow \Delta U = -\Delta W \)

3) Cycles

IDEAL GAS

- Identical, point masses
- Numerous

\[ PV = n \frac{2}{3} \langle K \rangle \]
\[ PV = nRT \]
\[ PV = NkT \]

\( \text{T is measure of } \langle K \rangle \)
Work done by ideal gas

\[ \Delta W = \int_A^B \frac{nRT}{V} \, dV = nRT \ln \frac{V_B}{V_A} \]

Molar specific heats

\[ \Delta Q = nC_v \Delta T \bigg|_V = \frac{3}{2} nRT \text{ ideal} \]
\[ \Delta Q = nC_p \Delta T \bigg|_P = \frac{5}{2} nRT \text{ ideal} \]

\[ C_p = C_v + R \]

Adiabatic processes

\[ PV^\gamma = \text{constant} \quad \gamma = \frac{C_p}{C_v} \]

\[ W = \frac{P_B V_B - P_A V_A}{1 - \gamma} \]
P-V-T Diagrams

Ideal Gas:

For non-ideal substances, phase transitions begin to be an issue...
MAKING IT REAL...

- finite sized molecules:
  - \( V \) - overall volume
  - \( b \) - volume occupied by molecules
  - \( V \rightarrow V-b \)
- short-distance attraction
  - \( P \rightarrow P + a/V^2 \)

\[
\left( P + \frac{a}{V^2} \right)(V-b) = nRT
\]

\( a \) and \( b \) are measurable constants.
\[ EV = \text{const} \]

\[ \frac{P_2}{V} = \frac{P_2}{V_2} = \frac{nR}{V} \]

\[ \frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{\text{nR}}{V} \]

\[ P_2 = P_1 \left( \frac{T_2}{T_1} \right) - 4 \]
2nd "LAW" OF THERMODYNAMICS

much subtly here... start gently!

TWO MOVIES:

- KINEMATICS MOVIE (bouncing ball) WORKS
  forward & backward -- equations time-invariant

- FRICTION MOVIE (block sliding down) DOESN'T
  the sliding block always gets hotter, forward
  or backwards in time -> an "arrow of time"
IRREVERSIBILITY...

- a feature of any process that generates heat
- things run down!

- THE FIRST LAW OF THERMODYNAMICS DOES NOT INCLUDE THIS
  waddling up to a snow drift to warm
  yourself is consistent with the 1st law
  ... but nature doesn't work this way...!

THERMODYNAMICS IS ONE-WAY
ESTABLISHES A DIRECTION
FOR TIME!

file this thought for a bit...
HEAT ENGINES

• Any device which converts thermal energy into mechanical energy.

• ALL ARE THE SAME:
  1. Heat is absorbed from a source at high T
  2. Work is done by the engine
  3. Waste heat is expelled to a cooler source

heat taken out to condense and re-use

Lots of devices take heat → work
cannon

“Engine” means a cyclical process
over & over again...
PERECT

All heat absorbed from the source is used for work.

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HERE... the engine is attached to the heat source. The engine's working substance is always at $T_H$.

From 1st Law:

$$\Delta U = \Delta Q - \Delta W \Rightarrow \Delta Q_H = \Delta W$$

Since $\Delta T = 0$

So

$$\Delta U = 0$$
Because the engine is cyclical... it goes back to its original state... \( T_i = T_f \)

So \( U_i = U_f \) \( \Rightarrow \) \( \Delta U_{net} = 0 \)

\[ \Delta Q = \Delta U + \Delta W \]

\[ Q_H - Q_c = W_{net} \]
**THERMAL EFFICIENCY**

\[ \varepsilon = \frac{\text{what you get}}{\text{what you paid}} \]

\[ \varepsilon = \frac{W}{Q_H} \]

\[ \varepsilon = \frac{Q_H - Q_c}{Q_H} = 1 - \frac{Q_c}{Q_H} \]

(Note: here \( Q_c \) is a positive number... in fact since heat leaves... \( Q_c \) is negative)

\[ Q_{\text{net}} = Q_H + Q_c \]

\[ = Q_H - |Q_c| \]

thermal efficiencies are not huge...

\[ \varepsilon_{\text{automotive}} \sim 20\% - 30\% \]

\[ \varepsilon_{\text{Diesel}} \sim 30\% - 40\% \]
PERFECT REFRIGERATOR

\[ Q_H \]

\[ Q_c \]
Such a perfect machine is impossible...

one of the many equivalent statements of
the Second Law of Thermodynamics.

2nd: It is impossible to construct a heat
gengine that, operating in a cycle,
produces no other effect than the
absorption of thermal energy from
a reservoir and the performance
of an equal amount of work.

("Kelvin-Planck Statement")

NEED TO "WASTE" SOME HEAT
A HEAT ENGINE IN "REVERSE"

Work must be done on the engine.

\[ Q_H + Q_C = W \]
\[ -Q_H = Q_C - W \]
\[ |Q_H| = Q_C + W \]

\( Q_H \) and \( W \) are negative in the system (engine).

Heat leaving hot > heat leaving cold
**Performance Coefficient**

\[ K = - \frac{\Delta C_p}{W} = - \frac{\Delta C_p}{\Delta H + \Delta C_p} = \text{COP} \]

2nd Law: It is impossible to make a refrigerator in a cycle, to produce no other effect than to transfer thermal energy from a cold object to a hot object.

\[ \text{COP} \neq \infty \]
Wotsamuch
ENGINE

HOT RESERVOIR
$T_h$

ENGINE

COLD RESERVOIR
$T_c$
Refrigerator

Some Freon family \*"refrigerant\* fluid

Low temperature
Low pressure

High temperature
High pressure

Heat Pump $\Rightarrow$ refrigerator, inside-out.

* not any more! 