Today:

1. Review $P$, New stuff
2. Review $P$, New stuff
3. New basics in physics: Energy
4. Ideal Gas Law: $pV = nRT$

Revisit Density, Air & Water

<table>
<thead>
<tr>
<th>$T^\circ C$</th>
<th>$\rho_w$ kg/l</th>
<th>$\rho_a$ kg/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.99987</td>
<td>1.29</td>
</tr>
<tr>
<td>10</td>
<td>0.99973</td>
<td>1.25</td>
</tr>
<tr>
<td>20</td>
<td>0.99823</td>
<td>1.20</td>
</tr>
<tr>
<td>35</td>
<td>0.99406</td>
<td>1.14</td>
</tr>
</tbody>
</table>

$\% \Delta \rho_w \quad 4^\circ \to 35^\circ \quad \% \Delta \rho_a \quad 0^\circ \to 35^\circ$

\[
\left(\frac{1000 - 0.994}{1000}\right) \times 100\% \quad \left(\frac{1.29 - 1.14}{1.29}\right) \times 100\%
\]

= 0.69% = 12%

Quite small $\% \Delta \rho_w$ much larger than $\% \Delta \rho_a$

BUT: Let's compare absolute changes in mass/unit vol.

\[
\Delta m = (1000 - 994) \text{ kg} = 6 \text{ kg} \quad (1.29 - 1.14) \text{ kg} = 0.15 \text{ kg}
\]

($\sim 13$ lb) ($0.3$ lb = $0.03$)

Later in class:
Why some systems resist mixing if temp varies?
Q: How much mass of air in classroom?

Guesstimate room Volume: 10 m wide
\times 10 m deep
\times 3 m high

\[300 \text{ m}^3 \times 1.2 \text{ kg/m}^3 = 360 \text{ kg} \]

\[
M_a = 360 \text{ kg} \times 800 \text{ lb}
\]

Revisit pressure \( P_a = \text{Pascal} = \text{N/m}^2 \)

\[1 \text{ Pa} = 10^3 \text{ kPa} = 10^{-5} \text{ bar} \]

\[1 \text{ bar} = 10^5 \text{ Pa} = 100 \text{ kPa} \]

\[1 \text{ atm} = 1.013 \text{ bar} = 101.3 \text{ m} \rho = 101.3 \text{ kPa} \]

\[= 760 \text{ mmHg (Torr)} \]

\[\leq 34 \text{ ft} \text{-H}_2\text{O} \]  

Water Barometric -34 ft-

1) Means can only pull \( \text{H}_2\text{O} \) up \( \leq 34 \text{ ft} \) by suction (Deeper wells = Push water up.)

2) Water pressure goes up 1 atm every 34 ft of depth: E.g.

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Pressure (psia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>34</td>
<td>30</td>
</tr>
<tr>
<td>68</td>
<td>45</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>

Hence difficult to dive \( \geq 100 \text{ ft} \) w/o advanced training or equipment.

Record Air Pressure Extremes on Earth

(Highest: 12/19/01, Mongolia 1086 m 32.06" Hg)

Lowest: 10/12/79 Typhoon "Tip" 870 m 25.7" Hg

Lowest (inside Tornado) Ft. Tornado South Dakota 840 m 25.1" Hg

(Note: All are corrected for elevation differences back to Mean Sea Level.)
ENERGY

In everyday experience in nature, three types:

1. Potential: Lift against gravity
   P.E. Stored or potential E
   \[ PE = mg \Delta h \]
   \[ 1 \text{kg} \] \[ 1 \text{m} = \Delta h \]

   P.E. can then be released into, say, kinetic E

2. Kinetic
   \[ K.E. = \frac{1}{2} m v^2 \]

3. Thermal (Heat)
   Due to heating or cooling

TRANSFER ENERGY by Either
Heat \( Q \) (Thermal) & Heat In(+) Heat Out(-)
Work \( W \) (Mechanical): Work In(-) Work Out(+)

UNITS ON ENERGY & TRANSFER
All same like Joule (J) = \( \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} \)

WORK

\( W \): Mechanical Transfer
Imagine ball at rest. Throw ball. Now has
\[ KE = \frac{1}{2} m v^2 \]
(Ex. 0 J \( \rightarrow \) 10 J)

How did this ball gain KE?
1. Accelerate ball \( \rightarrow \) Must Apply Force \( F = ma \)
2. And total KE is that FORCE \( \times \) DISTANCE it was applied

\[ W = F \cdot d \]
Units \( \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \cdot \text{m} \)
W & PE

WORK also creates P.E.:

\[ W = F \cdot d \]

\[ W = F_g \Delta h \]

\[ W = mg \Delta h = P.E. \]

\[ \uparrow \text{ work of lifting ends up as P.E. stored in the weight on the table} \]

Push weight off table, \( P.E \rightarrow K.E = mg \Delta h \)

\( \frac{1}{2} m v^2 \)

Mount Weight

Natural Example of Important Energy Transfers

SOLAR ENERGY IN: Heat evaporates water, rises. Then rain falls. Water has P.E. on mountain.

KE: Rivers have kinetic energy.

PE: Dam/reservoir stores energy.

KE: Hydroelectric generators spin \( \rightarrow \) Electricity.

So, "hydropower" is really "solar power" once removed.

HEAT, Q

Transfer

Two Laws of Thermodynamics

1. Energy always conserved. Just goes one form to another.

2. "You can't win."

All energy transfers involve loss of heat, "waste."

2. No Law: Means impossible to create or transfer work without some waste (loss of heat energy).

(No engine or device is 100% efficient)
Can add energy as heat, or remove E as heat

E.g. Work can turn KE into heat.

Ex: **Brakes**

\[
W = F \cdot d_{\text{rim}}
\]

\[
= \frac{1}{2} m v^2
\]

OK, at stop \( v = 0 \) \( KE = 0 \), but energy is conserved. Where'd it go?

\( \rightarrow \) **TURNED INTO** HEAT by FRICTION

Brakes are a “reverse engine” (and very powerful since all energy goes to heat)

Ex: Data 4-cyl cheap Nissan Versa

\begin{align*}
\text{Accel, } 0-60 \text{ mph } & \sim 10 \text{ sec.} \\
\text{Brake } 60-0 \text{ mph } & \sim 3.5 \text{ sec (50m)}
\end{align*}

\( \overline{\text{Brakes } 3 \times \text{ as powerful as the engine.}} \)

\begin{tabular}{l}
\text{Nissan 370Z NISMO ($60k$)} \\
\hline
\text{Accel } 0-60 \text{ mph } \sim 5.1 \text{ sec} \\
\text{Brake } 0-60 \text{ mph } \sim 2.2 \text{ sec}
\end{tabular}

\begin{tabular}{l}
\text{Note: engine } 2 \times \text{ better} \\
\text{Brakes } \sim 1.5 \times \text{ better} \\
\text{(starting to reach limits of tires)}
\end{tabular}
Note: Braking we discussed "Powerful"
(engine, brakes)

What is Power? \( \text{Power} = \frac{\text{Energy}}{\text{time}} = \frac{J}{s} = \text{Watt(W)} \)

Power is the rate of energy transfer.

E.g. 100 W light bulb uses 100 J/s to produce light and heat

Ex: The Nissan Versa

\[ m = 1,100 \text{ kg (curb weight)} \]

At 60 mph = 27 m/s

\[ KE = \frac{1}{2}(1,100 \text{ kg})(27 \text{ m/s})^2 \]

\[ = 401,000 \text{ J} \]

Average Acceleration Power: \( \delta \frac{401,000 \text{ J}}{10 \text{ s}} = 40,000 \text{ W} \times 0.00134 \text{ HP/W} \]

\[ 54 \text{ HP (horsepower)} \]

(Engine max @ 6000 rpm rated 107 HP)

Brakes Power: \( \frac{401,000 \text{ J}}{3.5 \text{ s}} \times 0.00134 \text{ HP/W} \)

\[ = 153 \text{ HP} \]
Heat Expands Gas, generates pressure
- Gas under pressure pushes piston, $F_p$
- Piston moves $d$
- $W = F_p \cdot d$  \( \Rightarrow \) WORK GENERATED BY HEAT

\[
p = \frac{F_p}{A}
\]
so $F_p = pA$

\[
W = pA d \quad A d = \text{Volume Increase} \quad \Delta V
\]

When a gas expands ($\Delta V > 0$) against pressure, the gas does work (+) on surrounding

- Gas loses energy & cools off (T drops)
  Expansion = cooling ($Q < 0$)

Conversely if gas is compressed ($\Delta V < 0$) by surrounding
the surrounding put work in (-) hence

- Gas gains energy & warms up
  Compression = heating ($Q > 0$)
IDEAL GAS LAW

- Atoms all independent;
- No interactions except random collisions
- Collisions perfectly "elastic" (no loss of KE)

Note that pressure due to force of gas molecules colliding with surface.

Some observations:

\[ \Delta V \]

Increase \( T \) (\( \Delta T > 0 \))

If \( V \) constant, \( p \) increase
If \( p \) constant, \( V \) increase
Or both \( pV \) can change in proportion to \( V \) and \( T \), etc.

So:

\[ p \propto T \]

\[ V \propto T \]

["\( \propto \)" means "is proportional to"]

And in general:

\[ pV \propto T \]

What if we ADD some more gas. Add "\( n \)" moles gas

\[ pV \propto nT \]

\[ \Rightarrow pV \] also increase

\[ \text{press.} \times \text{vol.} \propto \text{# of moles} \times \text{Temp} \]

Add in proportionality constant to make an Equation and make units work out

\[ pV = nRT \]

\( R = \text{"universal gas constant"} \)

Typical Units/Value: \( R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1} \)