March 25

New ME version of Engr. 260
- → After less duplication [4 → 3 credits]
- → Better mesh with 323.

Course Outline:

- Book
- ~~Calandar~~ Grades ⇒ Nominally a flexible curve.
- ~~Grades~~ Calandor
- OH → MWF 8 → 10; Any ~~pr~~ conflicts?
- HW:

- Make a little speach here -
  - Much of Engr. is about problem solving.
  - HW is your ~~way of~~ main way of learning material → Exams.
    - ↳ But also things that we cannot test for on exams (due to time), but still key.
  - Best to work separate until you get stuck. Will not tell you you cannot work together... cannot stop it. ~~Group dynamics are such that one person out of group~~
  - But: Note that there are two parts to problem solving
    - (a) Looking at problem and "seeing" the correct approach.
    - (b) Executing the solution.
  - Group dynamics are such that one of group will see approach ~~and will~~
  - Others will say "That's it" and everybody will solve problem.
  - Come exam time, the person who did the first part does OK, and the others cannot understand why they don't recognize any of the problems.
  - ~~Solutions in copy center - so turning HW in late won't help.~~
  - Hand out solutions, so late won't help.

- Quizzes: Need some explanation.
  - ~~In 260 → recitation every week.~~
  - Much is concept oriented.
  - Closed book quizzes show if you are missing ideas before exam.
  - Take home, honor system, no grades, but must turn in.
    - → Usually in recitation, but we don't have one.
  - ⇒ Pure learning tool.

No

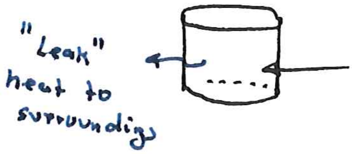
TA.

- Office Hours.
- Note that midterm dates are set. ~~Also, po~~
- Points score ⇒ Course graded on a flexible curve, depending on how well you do overall.

Basic Problem of Thermodynamics.

- First Law of Thermodynamics: Energy cannot be created or destroyed, it can only change form, move, and be accumulated.

e.g.



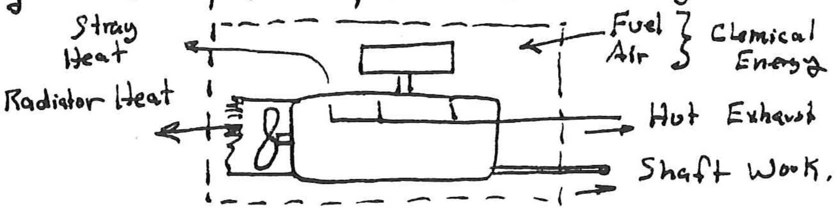
- 1 Kg H_2O
- Electric Heater

⇒ Add electric energy to container. (1 KW-hr)
⇒ Leak.
⇒ Water temp. goes up.

First Law ⇒ Electric Energy In − Energy out = Increase in water energy, as indicated by increase in T.

→ Principle seem simple, but in engineering we want to quantitatively predict the increase in T from a known amount of electrical energy ⇒ First law is tool to do ~~sim~~ this.

e.g. more complex example: automobile engine.

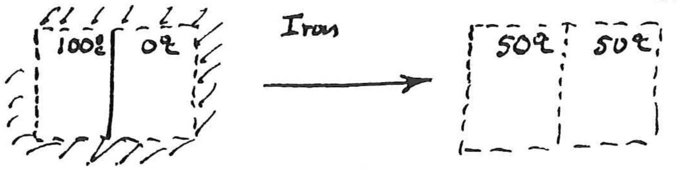


→ First Law says energy in = energy out ... its all got to balance.

→ Again, the complexity comes in when you want to get quantitative. ↳ what Engr. is all about.

- Second Law is much less intuitive: Direction of Energy Flow.

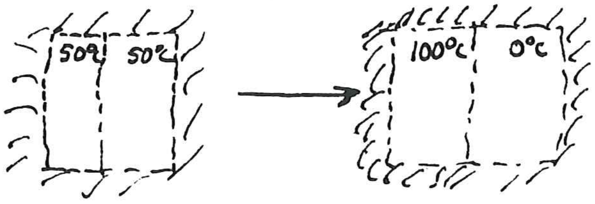
e.g.



1st Law:

Energy Lost by left side = Energy gained by right.

What prevents:

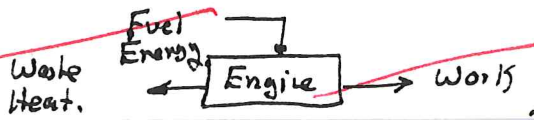


Energy gained by left = Energy lost by right.

Not first law: energy before is same as energy after for both cases.
→ This is where 2nd Law comes in.

low Thermo
ew →

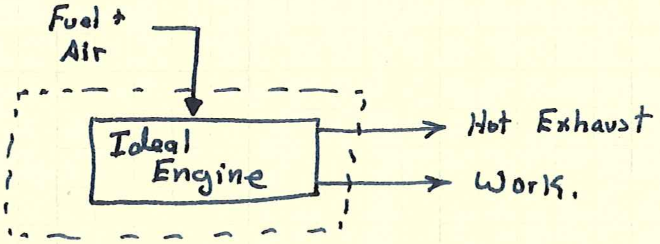
Other major example:



2nd Law ~~tells us~~ the maximum efficiency Fuel Energy → Work.
⇒ Cannot be 100%.

Other major example:

Ideal Engine:



1st Law:

$$\text{Energy in Fuel} = \underset{\underset{\text{(Room T).}}{\underset{0}{\uparrow}}}{\text{Energy in Hot Exhaust}} + \underset{\underset{\text{Max}}{\uparrow}}{\text{Work}}$$

Ideal

$$\text{2nd Law} \Rightarrow \text{Efficiency} = \frac{\text{Work} \quad \leftarrow \text{Useful product}}{\text{Energy in Fuel.} \quad \leftarrow \text{what you put in}}$$

So to summarize: 2nd Law tells you:

① Direction of processes.
② Maximum efficiency of heat engines.

} Put this to sleep for several weeks.

Very simple overview of units.

~~Temp: °C → Water melt 0°C Water boil 100°C~~
~~°F → 32°F 212°F~~

Normally work in SI units.

- Basic units : mass ~~Kg~~ Kilogram (Kg) $\cong$ 2.2 lb
  length meter (m) $\cong$ 3.28 ft.
  time Second (s)

Force = mass x acceleration

$$Kg \times m/s^2 = \frac{K\text{-}m}{s^2} = \text{Newton } (Nt).$$

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{Nt}{m^2} = \text{Pascal } (Pa) = \frac{Kg}{m\text{-}s^2}$$

But: Work a little in English.

$$\frac{14.7\ lb_f}{in^2}\left|\frac{32.17\ ft\text{-}lb_m}{lb_f\text{-}s^2}\right|\frac{Kg}{2.2\ lb_m}\left|\frac{144\ in^2}{ft^2}\right|\frac{3.28\ ft}{m} \cong 101,\overset{3}{\cancel{8}}00\ \cancel{Pa}\ \frac{Kg}{m\text{-}s^2}$$

$$= 101,\overset{3}{\cancel{8}}00\ Pa$$

$$\boxed{P_{atm} = 101.\overset{3}{\cancel{8}}\ KPa}$$

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⇒ Key to working in english units:

① Keep lb_f vs. lb_m separate
② Conversion factor to go from one to another is

$$\boxed{g_c = 32.17\ \frac{ft\text{-}lb_m}{lb_f\text{-}s^2}}$$

⇒ Will do a review of basic english units following quiz tomorrow.

~~Density: $\frac{mass}{volume} = \frac{Kg}{m^3} = \rho$~~

~~Water: $\frac{1\ gm}{cm^3}\left|\frac{Kg}{10^3\ gm}\right|\left[\frac{100cm}{m}\right]^3 = 1000\ Kg/m^3$~~

~~Work more with ~~density~~: specific volume $1/\rho$~~

Can work with <u>absolute</u> <u>pressure</u>. (best in thermo) and <u>relative</u> <u>pressure</u>.

~~Absolute refers to absolute~~

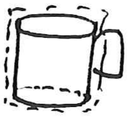
Pressure cooker has valve open to room. Gage reads 0 psi.

In each of these examples, we have

- What we have done above is identified a region for analysis: This is called a system:
- The key element in defining a system is to draw a control surface around it.
  - This way, you have a well-defined boundary across which you can worry about things entering and leaving system.
- Selection is kind of arbitrary. ⇒ Think about coffee cup in microwave.
  → Theoretically - it doesn't matter

(a)

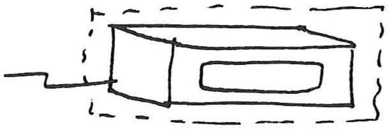
~~Coffee Cup in Microwave~~
Control Surface around cup.



Microwave radiation crosses boundary to increase energy of coffee

(b)

Control Surface around microwave



Electric energy crosses boundary to increase energy of ~~both~~ oven & contents.

⇒ You hope no microwave radiation cross boundary.

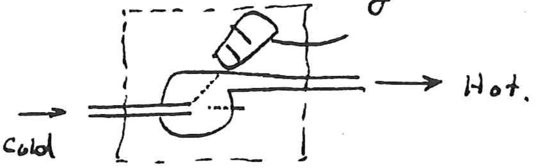
Three main types:

Closed System No mass can cross boundary, but energy can. - Coffee in Micro.

Isolated System Nothing crosses boundary. - Iron Blocks.

Open System Both energy and mass can cross boundary.

e.g. hair dryer. ~~electric pump.~~



Name an example of each in this room: (campus?)
- Chair →
- Thermos (ideally) - Isolated
- Radiator. - Open.

← Steel shell w. firecracker.

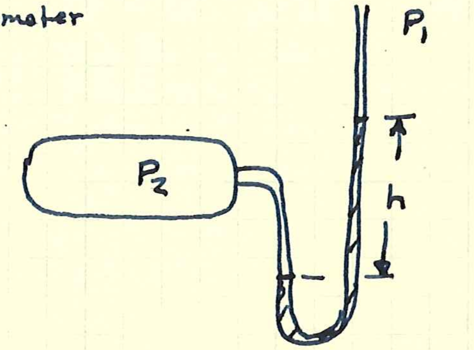
- Properties: Extensive vs. Intensive

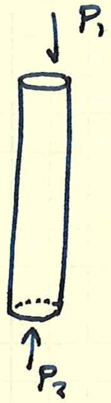
Extensive
- Depends on size of System
- Double Size, Double Property

Intensive
- Independent of Size
- Can be thought of as a prop. at a point.

Mass	x	
Temp		x
Pressure		x
Volume.	x	

Manometer





$\Sigma F = 0$

~~Down = $P_1 A$ +~~

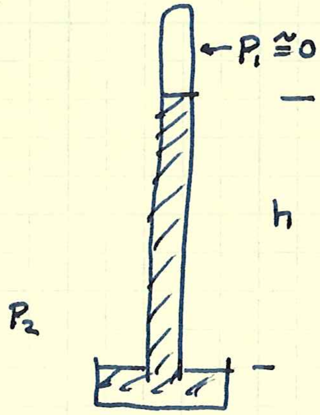
$\Sigma F = 0 \Rightarrow$ Down $= P_1 A + W_{fluid}$

Up $= P_2 A$

$W_{fluid} = mg = \rho_f \overset{Volume}{\widetilde{Ah}} g$

$P_1 A + \rho_f A h g = P_2 A \Rightarrow \Delta P = \rho_f g h.$

Mercury Barometers Special Case:



$P_2 = \rho_f g h$

Get h for 1 atm. pressure.

$P_2 = 101,300\ Pa \ \left(\frac{Kg}{m\text{-}s^2}\right)$

$$h = \frac{P_2}{\rho_f g} = \frac{101,300\ \cancel{Kg}}{m\text{-}\cancel{s^2}} \Bigg| \frac{m^3}{13,600\ \cancel{Kg}} \Bigg| \frac{\cancel{s^2}}{9.8\ m} = 0.76\ m = 760\ mm\ Hg.$$

→ What is absolute pressure? 14.7 psi ... ~~Absolute~~ |

$P_{abs} = 0$ only if your in a vacuum.

→ Heat Pressure cooker until it reads 20 psi.

① What is absolute pressure 34.7 psi.

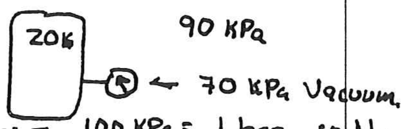
② What is gage really reading?

⇒ Difference between inside cooker and outside.

For gage $\boxed{P_{\cancel{atm}\ abs} - P_{gage} + P_{atm}}$

For vacuume gage.

Gage reads how far below atmospheric pressure you are.



→ Show bordon tube - Explain how it works

Insert 5.1

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Density = $\frac{mass}{Volume} = \frac{Kg}{m^3} = \rho$

→ Bar: = 100 KPa = 1 bar, so 1 bar ≅ 1 atm.

Water: $\frac{1\,gm}{cm^3}\left|\frac{Kg}{10^3\,gm}\right|\left[\frac{100\,cm}{m}\right]^3 = 1000\ Kg/m^3$ in SI units.

)

Don't like it.

Work more with specific volume $= \frac{1}{\rho} = \upsilon$ (little v)

For water $\upsilon = \frac{1}{\rho} = \frac{1\ m^3}{1000\ Kg} = 0.001\ m^3/Kg$.

Temperature: Good intuitive feel for this, but difficult to ~~quantify~~ give definition.

Definition is relative: Two objects are placed in contact.

⇒ Same T, no ~~heat flow~~ energy flow.

⇒ Different T, energy flows from hot → cold.

Temperature Scales:

	Ice Melts	Water Vaporizes
°F	~~32~~ 32°F	212°F
°C	0°C	100°C.

~~Absolute Temp~~

Temperature in a sense represents the kinetic energy of gas molecules in motion, or the vibrational energy of atoms constrained in a crystal. When all this energy is extracted so motion is zero, you are as cold as you can get ⇒ Absolute zero.

Scales that recognize this.

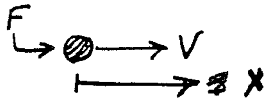
Kelvin = T °C + 273.15 (K)

Rankine = T °F + 460 (R).

0 K = absolute zero

Room T ≅ 25°C = 298 K. } →

Ch. 2 - Energy & First Law



Kinetic Energy:

Starting Points: Newton's Second Law: $F = ma$

$$= m\frac{dV}{dt}$$

Chain Rule: $$\frac{dV}{dt} = \frac{dV}{d\cancel{s}_{\,x}} \cdot \frac{d\cancel{s}^{\,x}}{\underset{\underset{V}{\uparrow}}{dt}}$$ (s = distance)

$$F = mV\frac{dV}{d\cancel{s}\,x}$$ Separate variables $$Fd\cancel{s}^{\,x} = mVdV$$

Integrate $$\int_{x\,s_1}^{\overset{x}{s_2}} Fd\cancel{s}^{\,x} = \int_{V_1}^{V_2} mVdV$$

$$\Rightarrow \underbrace{\int_{x\,s_1}^{\overset{x}{s_2}} Fd\cancel{s}^{\,x}} = \underbrace{\frac{1}{2}m\left(V_2^2 - V_1^2\right)}_{\text{Kinetic Energy}}$$

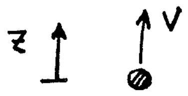
- Recognize from Physics: Force through distance ⇒ work

→ KE.

SI Units: $\frac{Kg - m^2}{s^2} =$ Joule.

Usually work with KJ = (1000 J).

Potential Energy:



Throw object upward against gravitational field, will eventually stop.

⇒ Force will be due to gravity. = mg.

$$\int_{z_1}^{z_2} F\,dz = \frac{1}{2}m\left(V_2^2 - V_1^2\right)$$

$$\underbrace{mg\left(z_2 - z_1\right)}_{\text{Potential Energy.}} = \frac{1}{2}m\left(V_2^2 - V_1^2\right)$$

Eg. Pitcher throws football straight up --- 100mph = 44.7 m/s
Neglecting air friction, how high?

m's cancel.

$$\left(9.81\frac{m}{s^2}\right)\left(z_2 - 0\right) = \cancel{\frac{1}{2}\left(44.7\frac{m}{s}\right)^2 - 0} = \frac{1}{2}\left[0 - \left(44.7\,\frac{m}{s}\right)^2\right]$$

What went wrong here? Pos # = Neg # ?

Forgot that direction of force is opposite to z ⇒ $\boxed{F = -mg}$

$$\boxed{Z = 101.8\text{ m}}$$

- Newton assumed that these were the only two forms of energy $\underline{KE + PE}$
- What happens when ball hits turf? $\left.\begin{matrix} KE = 0 \\ PE = 0 \end{matrix}\right\}$ Where did energy go?

- Needed to expand definition of energy ➡ Internal Energy - Energy associated with molecular motion.

→

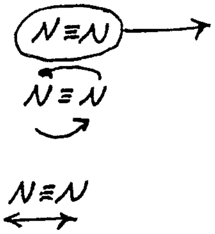
$$\text{Total energy} = KE + PE + U \longleftarrow \text{Internal Energy.}$$

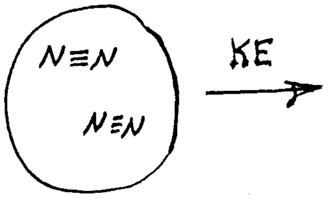
Air in room. $N \equiv N$ ~79%
$O = O$ ~21%

Internal Energy - Translation

Rotation

Vibration

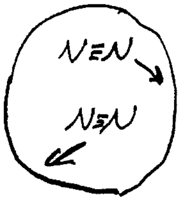




Translation

① Bring to halt

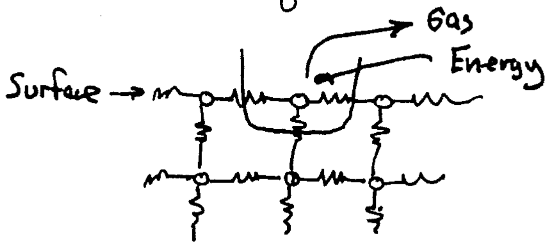
② Put KE Into N_2



- Molecular Velocities Increase
- Internal Energy goes up.
- External Manifestation is an increase in T, although U isn't proportional to T in general.

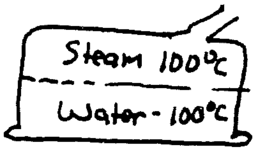
$$\frac{1}{2}mV^2 = \Delta U$$

- Solids and liquids are different because they are bound together.



- Here, internal energy is associated with vibration within the matrix.

- Vaporization - No change in T, but a large increase in U is needed to break bonds ⇒ ΔU associated with phase change



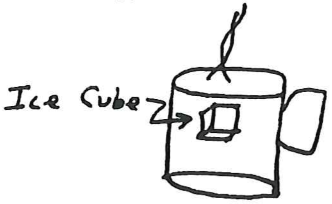
Some concepts:

State & Equilibrium

State: Condition of a System; characterized by <u>properties</u>
T, P, U, υ, etc.

Equilibrium: A system in balance that does not change with time.

Ignore heat loss (good thermos)
⇒ In equilibrium.



Not in equilibrium.
(Ice will melt).

⇒ General rule: Most systems are at equilibrium if P, T are same throughout system.

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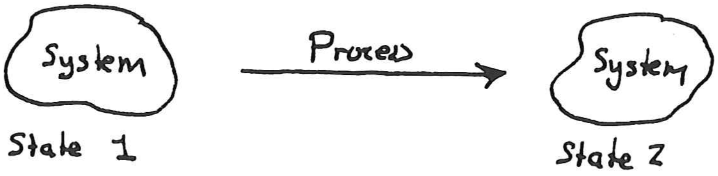
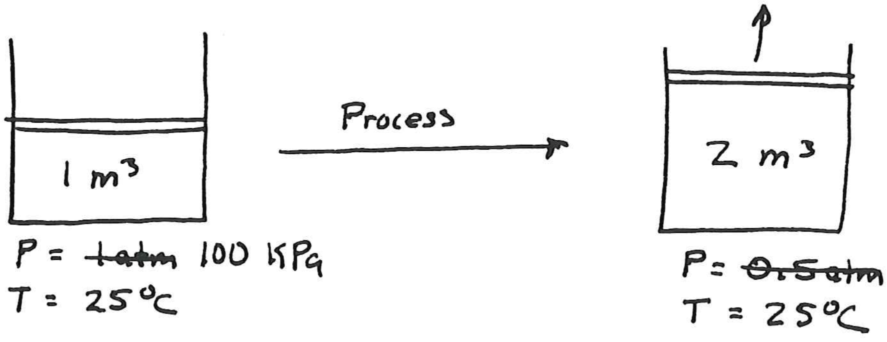
Process & Path.

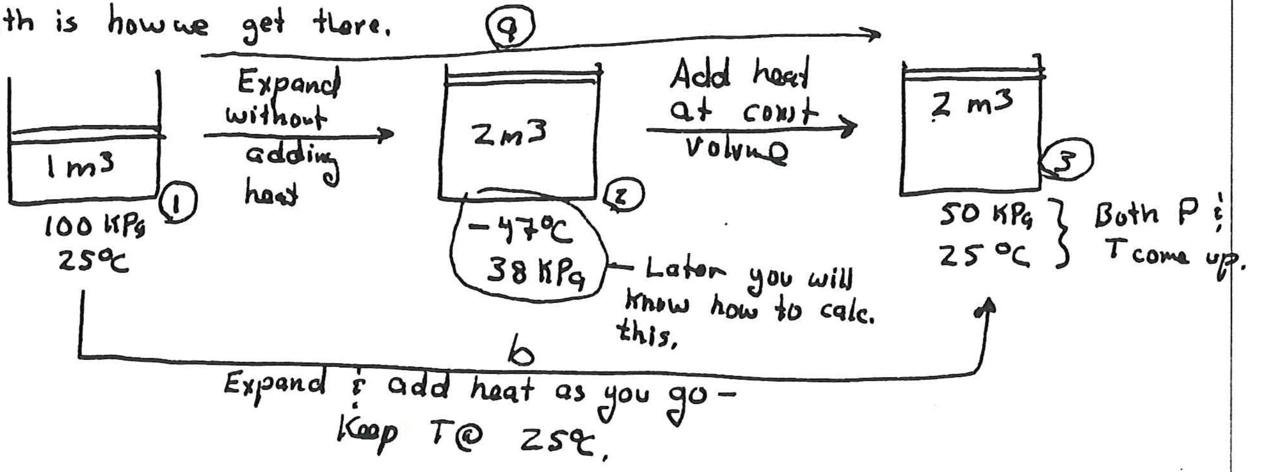


e.g.



Here, process was an isothermal expansion.

Path is how we get there.



- The work that we get out of the piston/cylinder system (F•D) will depend on the path. Since this is what runs your car- you are <u>very</u> interested in it.

March 30 Talk about work:

$$W = \int_{S_1}^{S_2} F\,ds$$

Sign convention: Work done <u>by</u> a system is positive

+Work:	- Work
Car engine	Refrig. Comp.
Gas Turbine	Pump.
Power Plant	Blender.

e.g. our piston/cylinder system is expanding ; doing work on surroundings, so $W > 0$.

Work done <u>on</u> a system is negative

e.g. if we had compressed our piston/cylinder system, work would be negative.

Back to equation above: $P = \frac{F}{A} \Rightarrow F = PA.$

$$W = \int_{S_1}^{S_2} \underbrace{PA\,ds}_{dV \leftarrow (\text{Volume})} = \int_{V_1}^{V_2} P\,dV$$

To evaluate this integral, you need to know the relation between P and V.

For path ⓐ ① → ② $PV^{1.4} = \text{constant}$ ⟸ Much later will define where this came from.

$$P_1 V_1^{1.4} = (100\,\text{KPa})(1\,\text{m}^3)^{1.4} = 100$$

$$P = \frac{\text{Const}}{V^{1.4}} - \frac{100}{V^{1.4}}$$

$$W_{1-2} = \int_1^2 \frac{100}{V^{1.4}}\,dV = -\frac{100}{0.4}\left[\underset{\substack{\uparrow \\ 2\text{m}^3}}{V_2^{-0.4}} - \underset{\substack{\uparrow \\ 1\text{m}^3}}{V_1^{-0.4}}\right] = 60.54\ \text{KPa-m}^3$$

$$60.54\ \frac{\text{KPa-m}^3}{} \left|\frac{10^3\,\text{Pa}}{\text{KPa}}\right| \frac{\text{Kg}}{\text{Pa-m-s}^2} \left|\frac{\text{s}^2\text{-J}}{\text{Kg-m}^2}\right| \frac{\text{KJ}}{10^3\,\text{J}} = 60.54\,\text{KJ}$$

$$\boxed{1\ \text{KPa-m}^3 = 1\ \text{KJ}}$$

② → ③ $W_{2-3} = \int_2^3 P\,dV = 0$ ... no volume change.

Path ⓑ Here $PV = \text{const}$

$$P_1V_1 = (100\,\text{KPa})(1\,\text{m}^3) = 100 = \text{const.} \Rightarrow P = \frac{\text{Const}}{V}$$

$$W = \int_{V_1}^{V_3} \frac{100}{V}\,dV = 100 \ln\left[\frac{V_3}{V_1}\right] = 69.31\ \text{KPa-m}^3$$

$$= \boxed{69.31\ \text{KJ}}$$

(60.54 KJ before)

Same Volume change, but different W... Why?

⇒ Adding heat while you expand keeps average pressure higher ⇒ more W out of $\int P\,dV$.

Other types of Work outlined in book:

Extension of Solid Bar — ~~Same as spring~~ Stress × Strain.
Extend Liquid Film — Surface Tension × Extensio
Shaft Work — Torque × Angular Displacement.
Electrical — Volts × ~~Amps~~. Charge.

First Law - Formal Definition:

$$\underbrace{\text{Sum of all energy flows crossing boundary of system}}_{\text{Resolve all energy flows into two components}} = \text{Change in System Energy.}$$

System.

$$\boxed{\begin{array}{l} \underset{\text{(heat)}}{Q} - \underset{\text{(Work)}}{W} = \Delta E_{sys.} \\ \qquad\qquad\qquad \hookrightarrow = \Delta U + \Delta KE + \Delta PE \end{array}}$$

Q is heat. Thermo definition → Energy which flow because of a difference in temperature.

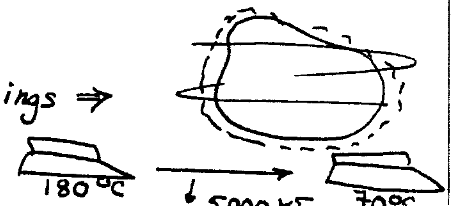
Term often misused: Often say a hot ~~object~~ Iron has a lot of heat.

→ What it really has is a lot of energy

→ As it cools, it loses energy to surroundings ⇒

This energy flow is heat. (formally).

(here the 5000 KJ)



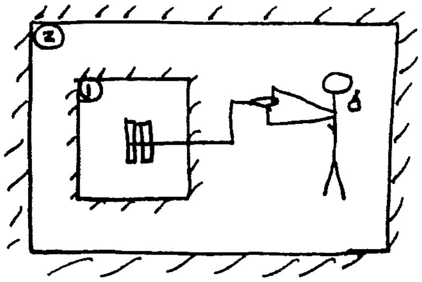
Sign Convention (Purly Arbitrary)

Heat Going Into System $Q > 0$

Heat Leaving System $Q < 0$

~~Three ways of expressing~~ — O

Heat vs. Work.

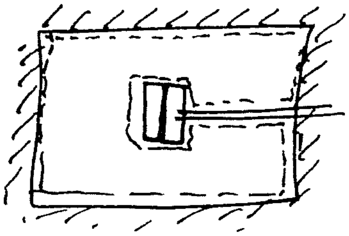


Features

- Both Enclosures insulated, no heat flow.
- Friction Plate.

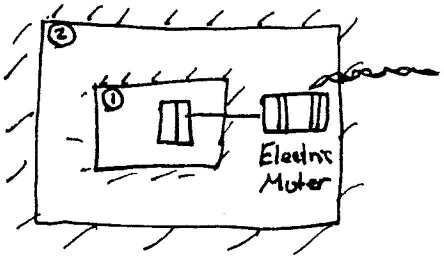
System	1	2
~~Open Closed Isolated~~ }?	~~Closed~~	~~Isolated~~.
Energy Crossing Boundary	Work	0
Sign	"–"	
Open Closed Isolated }?	Closed	Isolated.

Redo System ①



Energy Crossing Boundary	Heat
Sign	"+"
Type	Closed

Redo Again



System	1	2
Energy Crossing	Work	Work.
Sign	"–"	"–"
System	Closed	Closed.

April 5

Key Points of Chapter 2:

First Law $Q - W = \Delta U + \Delta KE + \Delta PE$

Q Energy Flow driven by temperature difference

W Other energy flows.
→ Boundary work due to expansion or contraction

$$W = \int_{V_1}^{V_2} P dV$$

Note sign convention.

U = energy contained in molecular structure
→ molecular velocity
→ Vibration, etc.

Alternate forms: $\delta Q - \delta W = dU$ differential

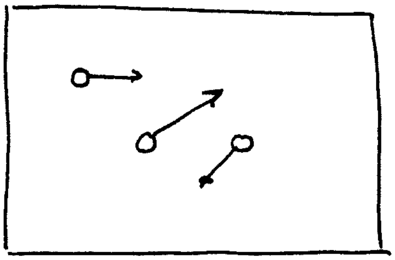
$\dot{Q} - \dot{W} = \frac{dU}{dt}$ in terms of time.

All express the idea that "Sum of Energy Flows across Boundary" = "Change in Energy inside System"

For a cycle: You start & end at same place, so $\Delta U = 0 \Rightarrow \boxed{Q = W}$.

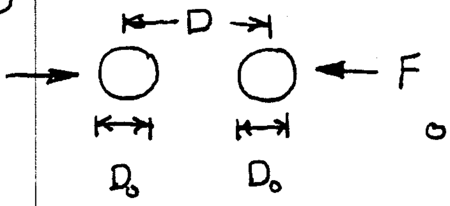
Chapter 3 - Properties ⇒ Glue that binds thermo together.

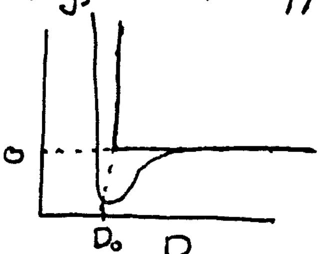
- ~~Work for~~
- Work with pure substances ⇒ Fixed chemical composition: e.g., N_2 or H_2O.
- Phases: Gas, liquid, solid.
- Gas: Think of billiard table:



→ Low-density molecules travel unimpeded.
→ Interactions are through occasional "collisions"
→ Microscopically, what happens during collision?

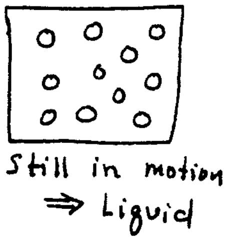
April 1



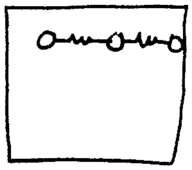


- Long ways away, no force.
- At $D = D_0$ force becomes infinite
- Actually, they initially attract, then repel.

- If you compress, or cool the gas enough, all of the molecules will pack together in the attractive region... i.e., they will stick.

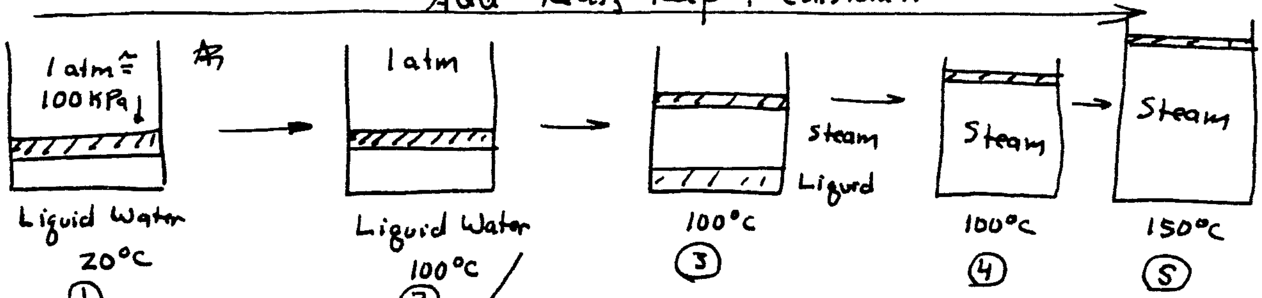

Still in motion
⇒ Liquid

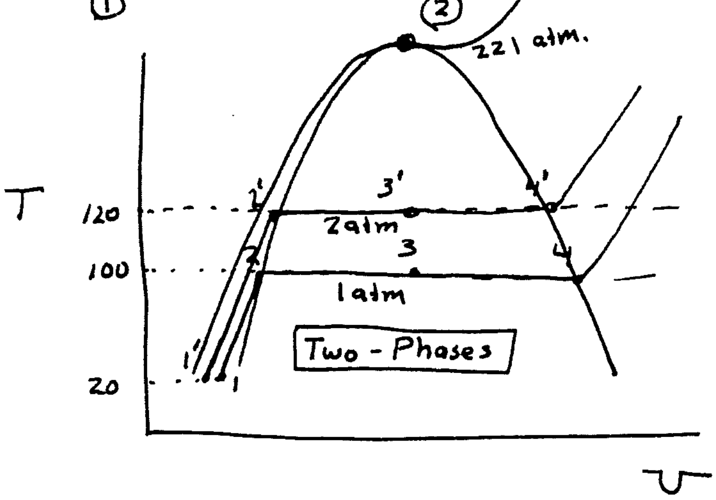
or


No change in position- solid.

Look at Phase Change: ⇒ Phase Diagram.

Add heat, Keep P constant.





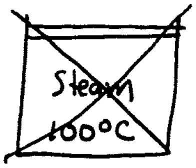
- Now repeat at 2 atm.
- Get whole family of curves
- Join phase boundaries. ⇒ Two-phase dome.
- ~~→ Critical point.~~

⇒ Boiling point depends on P - Harder to cook in Denver.

⇒ Critical Point: Unique : P = 22.09 MPa ≅ 221 atm.
T = 374.1 °C.

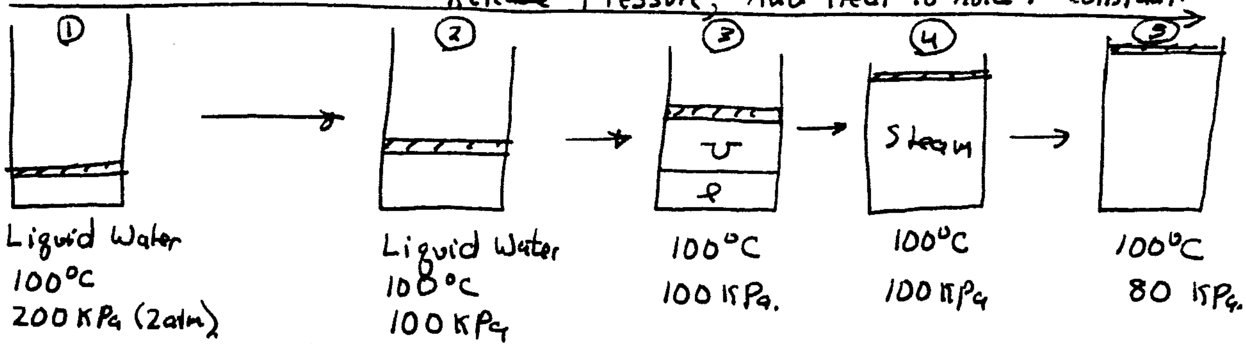
⇒ At higher T, go from "liquid" to "gas" without a distinct phase change.

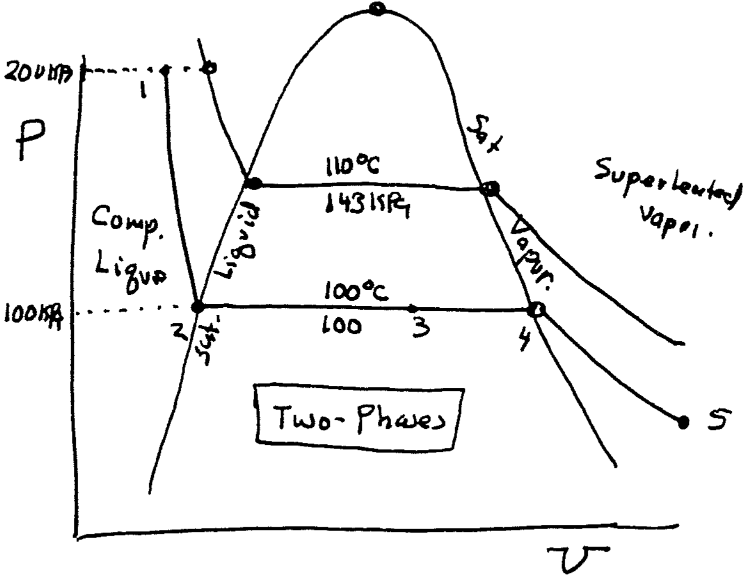
Now do another thought experiment:



Second Thought Experiment:

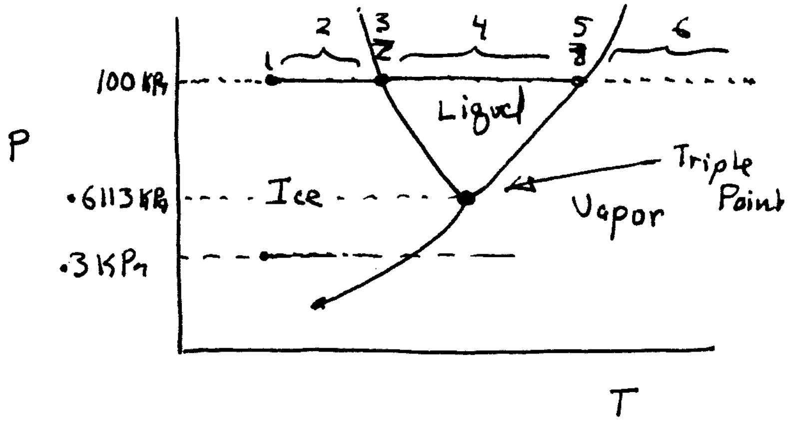
Release Pressure; Add Heat to hold T-constant.





- Now repeat at ~~200°C~~ 110°C
- Get Family of curves
- Two-Phases.
- Critical Point
- Saturated liquid
  - Just ready to make vapor.
- Saturated vapor
- Superheated Vapor
- Compressed Liquid

Hybred of these two plots is the P-T diagram:

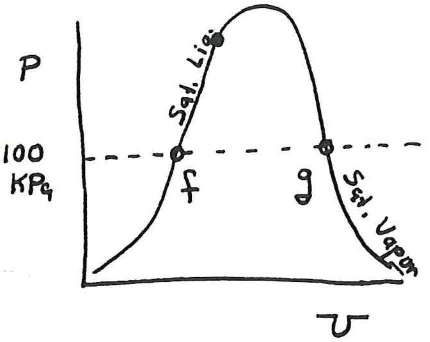


① Start with ice. -40°C.
② ~~Melts.~~ Ice Heats
③ Melts 0°C
④ Water heats
⑤ Boils 100°C
⑥ Steam Heats

At P=0.3 KPa ~~Sat~~
Ice → Vapor. Sublimes.
⇒ Just Like dry ice
• ⇒ Triple Point.

Property Tables:

Saturated Liquid / Sat. Vapor ⇒ Table A-$\overset{5}{\cancel{3}}$ for water/Steam.

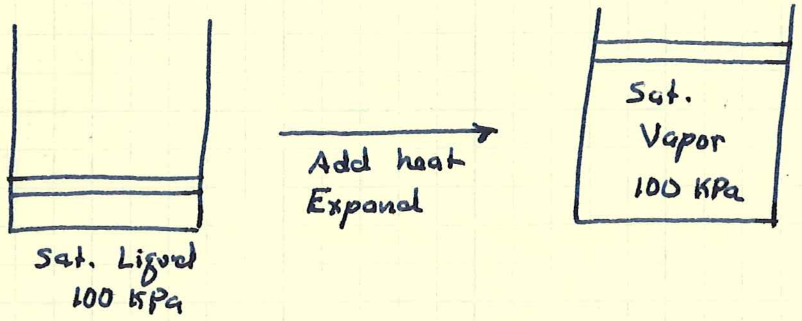


		Specific Volume		Internal Energy	
		Liquid	Vapor	Liq	Vap
P, KPa	T °C	v_f m3/Kg	v_g m3/Kg	u_f KJ/Kg	u_g KJ/Kg
100	99.63	.001043	1.694	417.36	2506.1
150	111.4				

~~h → 2417.46 → 2675.5~~

- Note that P & T are not independent here
  - Given one, you have the other
- Table A-$\cancel{3}$4 has same information, but with T as evenly-spaced, rather than P as in Table A-$\cancel{3}$5

Example: Start with 0.1 Kg Sat. Liquid @ 100 KPa



① Change in volume?

$$V_1 = m v_1 = m v_f = \frac{0.1\ \text{Kg} \,|\, 0.001043\ \text{m}^3}{\text{Kg}} = 1.043 \times 10^{-4}\ \text{m}^3$$

$$V_2 = m v_2 = m v_g = \frac{0.1\ \text{Kg} \,|\, 1.694\ \text{m}^3}{\text{Kg}} = 0.1694\ \text{m}^3$$

② How much work?

$$W = \int_{V_1}^{V_2} P\,dV = \cancel{P(V_2 - V_1)} = \int_{v_1}^{v_2} m P\,dv = mP(v_2 - v_1)$$

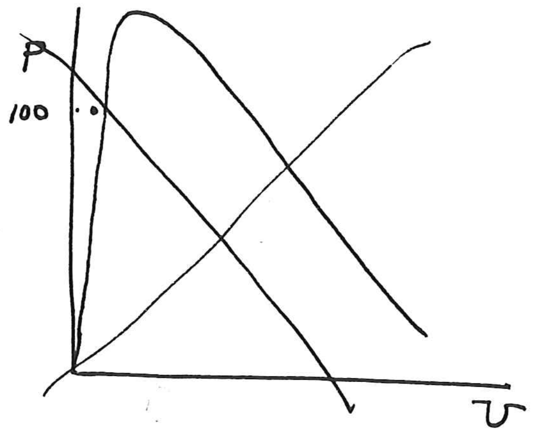
$$= \frac{0.1\ \text{Kg} \,|\, 100\ \text{KPa} \,|\, 1.694 - 0.001043\ \text{m}^3}{\text{Kg}} = \overset{16.94}{\cancel{16}}\ \text{KPa-m}^3 = \underset{16.94}{\cancel{16}}\ \text{KJ}$$

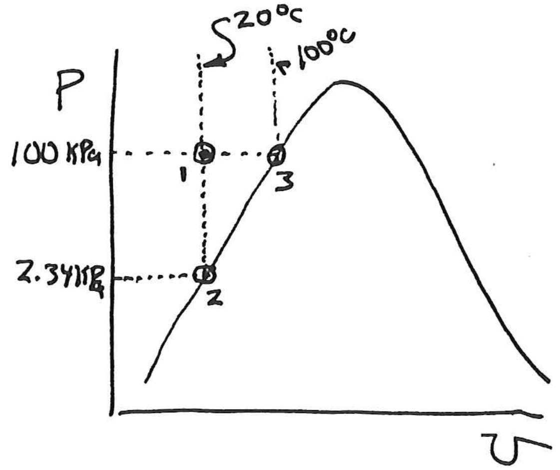
The reason one doesn't often have to use these tables is that there is an excellent approximation that avoids their use.

⇒ "Compressed Liquid Property" = "Saturated Liquid Property at Same T"

Glass of water on table $P = 100\text{ KPa}$, $T = 20°C$. Find v.

- It's a compressed liquid, but there is no entry for 100 KPa in the tables.
  (Lowest pressure given is 2500 KPa).
- Look at P-v diagram.





Question: Which is the better approximation for state ① → ② or ③ ?

- If I take my glass of water and heat it to 100°C, volume will increase, energy will definitly go up.
- If I take my glass, and reduce the pressure: v stays almost the same, u stays the same ⇒ Props @ 2 almost the same as props @ 1.

April 5

— — — — — — — —

Same thing as saying that T affects properties of compressed liquid, but P doesn't much.

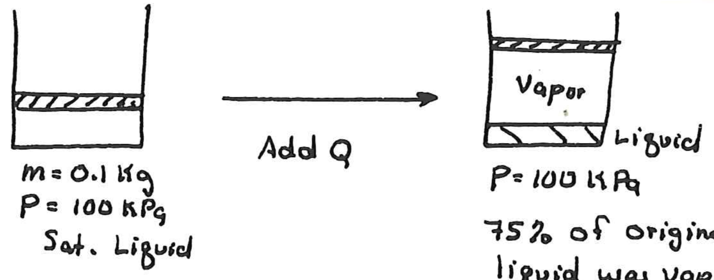
e.g. At 2500 KPa, 20°C ⇒ $u = 83.80$ KJ/Kg.
@ 20°C ⇒ $u_f = 83.95$ KJ/Kg

⇒ Tables are used to cover properties in and near two-phase region.

⇒ In the gas-phase, at a distance away from the dome, you can replace the tables with equations –

April 3 3

Now return to our example!



75% of original liquid was vaporized
25% remains.
] mass basis

Find volumes,
V_2, W ~~P_2~~
U_2

Definition: Quality $= X \equiv \dfrac{\text{mass vapor}}{\text{mass liquid} + \text{mass Vapor}}$ } For two-phase mix.

$$V_T = V_f + V_g$$

$$= m_f v_f + m_g v_g$$

$$= m_T\Big[\underset{\underset{1-X}{\uparrow}}{\frac{m_f}{m_T}} v_f + \underset{\underset{X}{\uparrow}}{\frac{m_g}{m_T}} v_g\Big]$$

$$= m_T\big[(1-x)v_f + x v_g\big] = m_T\big[v_f - Xv_f + Xv_g\big] = m_T\big[v_f + X(\underbrace{v_g - v_f}_{v_{fg}})\big]$$

So average specific volume of two-phase mixture is. $\quad v_{avg} = v_f + X(v_g - v_f)$

Same follows for all other properties $\quad u_{avg} = u_f + x(u_g - u_f)$

$\Rightarrow h, s \quad$ ~~$h_{avg} = h_f + x(h_g - h_f)$~~

~~$v_2 = 0$~~ $\overset{V_2}{\cancel{u}_2} = (\cancel{0.1\,Kg})\big[0.001043 + (0.75)[1.694 - 0.001043]\big]$

$V_2 = m v_2 = \dfrac{0.1\,Kg \,|\, 1.27\ m^3}{kg} = \overset{1.27\ m^3}{\cancel{0.127\ m^3}} \Rightarrow 0.127\ m^3$

$u_2 = 417.36 + 0.75[2506.1 - 417.36] = 1983.9\ KJ/Kg.$

$W = \displaystyle\int_{V_1}^{V_2} P\,dV = \cancel{mP(v_2 - v_1)} = \dfrac{\overset{0.1\ Kg}{\cancel{0.1\ Kg}} \,|\, 100\ KPa \,|\, \overset{1.27}{\cancel{0.127}}\,m^3 - \overset{-\ .001043}{\cancel{1.043\times10^{-4}}}\ m3}{\cancel{4} \qquad\qquad Kg}$

$mP(v_2 - v_1)$

$= 12.69\ KPa\text{-}m3$

$= 12.69\ KJ$

Can work in other direction:

2 Kg H_2O
Sat. Liquid

$V_2 = 100\ V_1$

Find u_2

Two steps: $v_2 = v_f + x_2 v_{fg}$

$$\Rightarrow \quad x_2 = \frac{v_2 - v_f}{v_{fg}}$$

At 100 kPa, sat. liquid: $v_f = 0.001043 \frac{m^3}{Kg} = v_1$

Given $v_2 = 100 v_1 = 0.1043\ m^3/Kg$

$$x_2 = \frac{0.1043 - 0.001043\ m^3/Kg}{1.694 - .001043\ m^3/Kg} = 0.061$$

$$\Rightarrow u_2 = u_f + x_2 u_{fg} = 417.36 + 0.061\left[2506.1 - 417.36\right] = 544.8 \frac{KJ}{Kg}$$

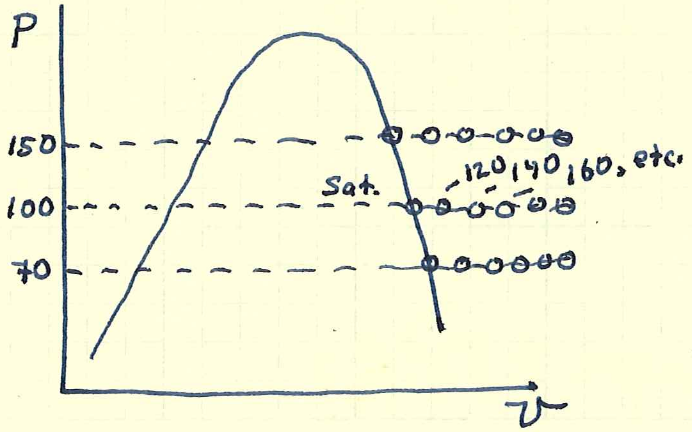
Next, what happens if we repeat problem, but with $V_2 = 2000 V_1$?

$$v_2 = 2000\, v_1 = 2000\left[0.001043\ m^3/Kg\right] = 2.09\ m^3/Kg.$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{2.09 - .001043}{1.694 - .001043} = 1.23$$

So $v_2 > v_g$

⇒ Means we are outside of two-phase region
⇒ Superheated steam
⇒ Table A-6



P = 0.1 MPa (100 KPa)

T	v	u	~~h~~
Sat	-	-	
150	1.9364	2582.4	
200	2.172	2658.1	

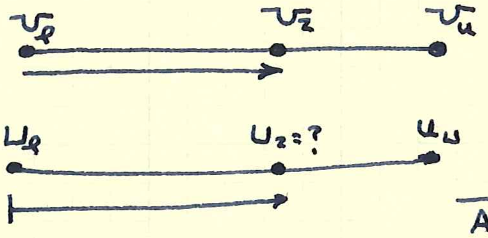
Perform linear interpolation to get u_2

$$u_2 = \underbrace{\left[\frac{2.09-1.9364}{2.172-1.9364}\right]}\left[2658.1-2582.4\right] + 2582.4$$

$= 2631.75$

$$T_2 = \left[\text{Same}\right]\left[200-150\right] + 150$$

$= 182.6°C$



Term in brackets is fractionally how for you are along this line.

Apply same fraction

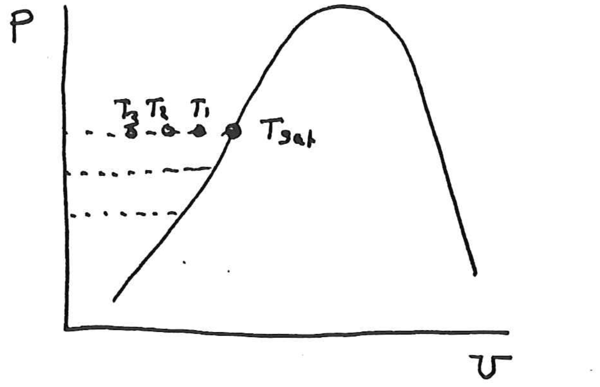
Should get to where you can do this without writing down intermediate steps.

⇒ Not limited to water - have these tables for other substances → Refrigerants R-12, R-134a }

⇒ So entire region is covered.

→ ~~A-5~~ A-7

Compressed Liquid: → Can usually avoid using these tables!



$P = 2.5$ MPa.

$\underline{T}$ $\underline{v}$ $\underline{u}$ $\underline{h}$

e.g., go down in ocean ~2 miles - how much has water been compressed?

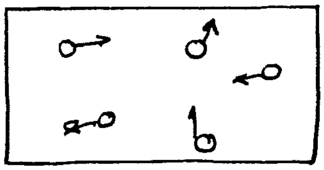
$P = 300$ atm ≅ 30 MPa., $T = 20°C$ } → $v = 0.0009886\ m^3/kg$

$P = 100$ kPa, $T = 20°C$ } → $v = 0.0010018\ m^3/kg$

→ 1.34% Compression.

Ideal Gas

Go back to frictionless Pool Table -



Here let:

$T \sim u \sim \cancel{\frac{1}{2}mv^2}\ KE \sim \frac{1}{2}mv^2$

$P \sim$ [Number of wall collisions] X [Momentum of Collisions]

$V \sim$ [Area of Table]

$\upsilon =$ [Area / Ball]

First operation: ~~double the number of balls.~~ reduce area by factor of 2 - Same T.

~~$V_1 = V_2$~~ $V_2 = 0.5 V_1$

but $\underline{\upsilon_2 = 0.5\, \upsilon_1}$

Also, number of wall collisions doubles: $P_2 = 2 P_1$

So in general $\frac{P_2}{P_1} = \frac{\upsilon_1}{\upsilon_2}$ for constant T. $\Rightarrow$ $P_2 \upsilon_2 = P_1 \upsilon_1$

Next operation: Double Temperature:

$\Rightarrow$ Double KE $KE_2 = 2 KE_1$

$$\frac{1}{2} m V_2^2 = 2\left[\frac{1}{2} m V_1^2\right] \Rightarrow V_2 = 1.414 V_1$$

$\Rightarrow$ Note that we have not doubled velocity.

What happend to ~~E~~? υ? $\upsilon_1 = \upsilon_2$

How about P? $P = [\text{No. of Collisions}] \times [\underbrace{\text{Momentum}}_{mV}]$

$\Rightarrow$ Average momentum increase by 1.414
$\Rightarrow$ No. of collisions increases by 1.414 } P double.

$P_2 = 2 P_1$

So in general: $\frac{P_2}{P_1} = \frac{T_2}{T_1} \Rightarrow \frac{P_2}{T_2} = \frac{P_1}{T_1}$

Combine these together for a fixed mass: $\Rightarrow$ $\frac{P_2 \upsilon_2}{T_2} = \frac{P_1 \upsilon_1}{T_1} = \text{constant} \Rightarrow \overline{R}$

Carry this one step further: $P\upsilon = \overline{R} T$

Universal gas constant,