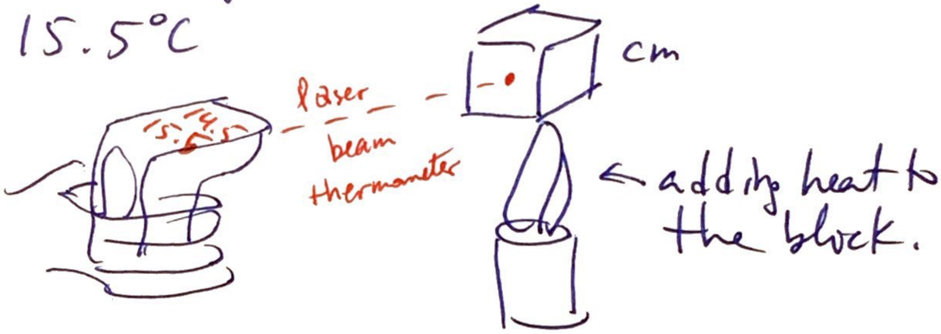
Chapter 14 Heat

Heat is energy! (Joules) (N-m), (calorie) physics

(BTU), { dietary calorie is 1000 physics calories

* calorie (cal)

SI. A calorie is the heat needed to increase by 1 deg celcius one gram of H_2O from 14.5°c to 15.5°C



- 1 British thermal Unit = heat needed to raise 1 lb of water by one deg Farenheit

USCS USCS USCS

↓

- 1 therm = 100,000 BTU

* mechanical energy → ($W = F \cdot d$, $\frac{1}{2}mv^2$, mgh)

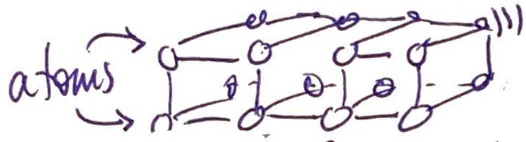
$$4.186\ J = 1\ cal$$

↖ thermal energy

(*) Heat is transfered from one object to the another.

- Internal energy - sum of all energies contained in an object.

Solid



← interaction is really strong

(lattice)

(wiggle but do not wander

Liquid

← interaction is strong

(can wiggle but mostly they wander)

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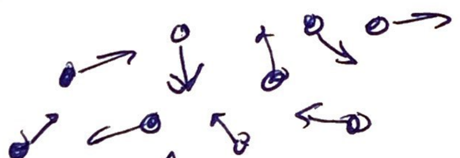
gas



← interaction is weaker. (PE)

(wiggle but <u>wander alot</u>)
↳ KE

- rotational $\frac{1}{2}I\omega^2$
- vibrational $\frac{1}{2}kx^2$
- translation $\frac{1}{2}mv^2$

The internal energy = sum of all KE, PE, etc.

* Internal energy on an atomic scale is written as $U = \frac{1}{2}m\overline{v^2}$ for translational KE. only

for N moles of atoms/molecules

$$U = N\left(\frac{1}{2}m\overline{v^2}\right)$$

but in Chp 13 : $\frac{1}{2}m\overline{v^2} \equiv \frac{3}{2}kT$

Temperature is motion

$\Rightarrow$ $$U = \frac{3}{2}nRT$$ Ideal monoatomic gas.

* Specific heat : different materials absorb heat differently

• specific heat (based on the material in use)

$$Q = mc\Delta T$$

- m: mass of the material
- c: specific heat of an material
- ΔT: change of temperature

• The specific heat is the amount of heat to change one kg of materia by one deg celcius

To find "c" for a material we use the formula backwards:

$$C = \frac{Q}{m\Delta T}$$

Q ← add heat (stimulus)

$m\Delta T$ → (response) by how much does the T increase

Units

$$[C] = \frac{J}{kg\,°C}$$

or

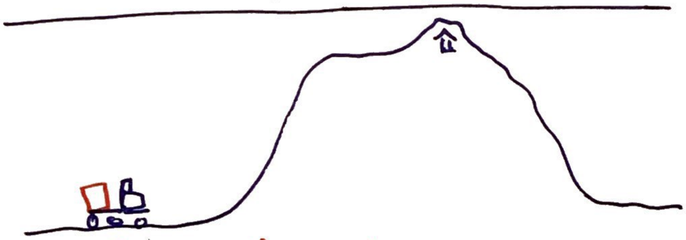
$$\frac{cal}{gm\,°C}$$

same cal/g/°C ⇕ (kcal / kg °C)

Table

	$c\left(\frac{J}{kg\,°C}\right)$	$c\left(\frac{kcal}{kg\,°C}\right)$
Al	900	0.22
Cu	390	0.093
H_2O	4186	1.00 Stnd.
Ice	2100	0.50

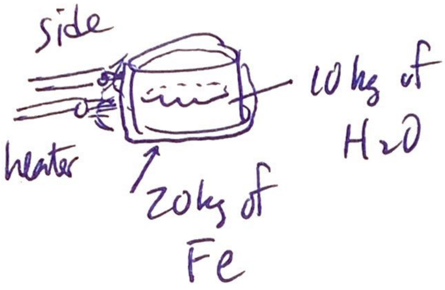
Quiz: You need to deliver a warm object from ground level to the frozen top of a high mountain in order to keep your buddies alive in a cabin that has no heat source. What material should we use to place on our 1-ton pickup truck?



Ans: Water! is the best way to transport heat.

Q: ← what material do I choose to deliver the most Heat?

EX How much heat is needed to warm a 20kg Vat of Iron, full of 15 kg H_2O, from 10°C to 90°C?



$$Q_{TOT} = Q_{Fe} + Q_{H_2O}$$

$$= m_{Fe} C_{Fe} \Delta T + m_{H_2O} C_{H_2O} \Delta T$$

$$= (m_{Fe} C_{Fe} + m_{H_2O} C_{H_2O}) \Delta T$$

populate

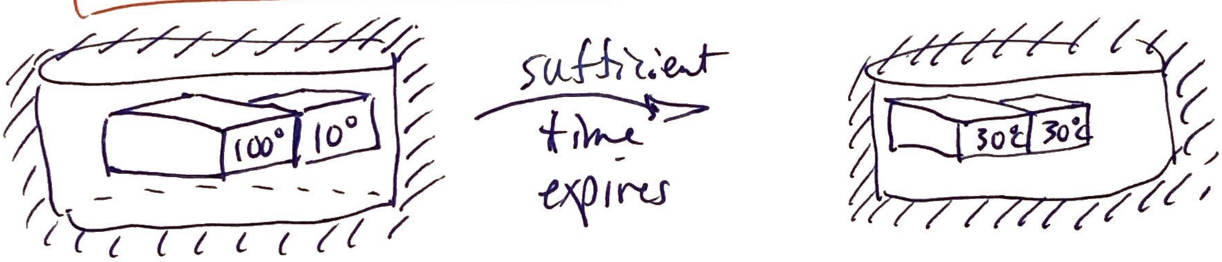
$$Q_{TOT} = \left(20kg \cdot 0.11 \frac{kcal}{kg\,°C} + 10kg \cdot 1 \frac{kcal}{kg\,°C}\right)(90°C - 10°C)$$

$$= \left\{(2.2 + 10) \frac{kcal}{°C} \cdot 80°C\right\}$$

$$\boxed{Q_{TOT} = 976 \text{ kcal}}$$

* Calorimetry

0th Law of thermodynamics: After an infinite amount of time, all materials in a closed system will have the same temperature



insulated container

"calorimeter"

No Heat escapes or enters.

"Heat flows from hot to cold".

EX 200 cm^3 of hot tea @ 95°C is poured into a 150 g glass cup initially @ 25°C.

Q: What is the final (equilibrium) Temperature?

Tea	Cup	
95°C	25°C	? °C
200 g	150 g	

Heat lost by the hot tea is the heat gained by the cup

• Cons. of energy: $m_{Tea} C_{Tea} \Delta T = m_{cup} C_{cup} \Delta T$

$$(0.2\,kg)\left(4186 \frac{J}{kg\,°C}\right)\underbrace{(95° - T_{eq})}_{(+)} = (0.150\,kg)\left(840 \frac{J}{kg\,°C}\right)\overbrace{(T_{eq} - 25°C)}^{(+)}$$

↑ final − init

$$(0.2)(4186)(95) + (0.150)(840)(25) = (0.2)(4186)T_{eq} + (0.150)(840)T_{eq}$$

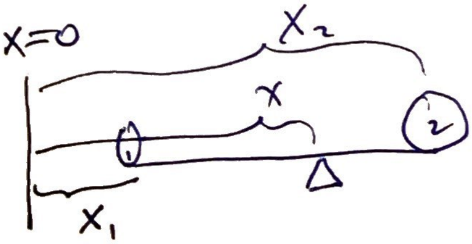
$$T_{equilibrium} = \frac{(0.2)(4186)(95) + (0.15)(840)(25)}{(0.2)(4186) + (0.15)(840)}$$

$$= \frac{79{,}534 + 3150}{837.2 + 126}$$

$$= \frac{82{,}684}{963.2}$$

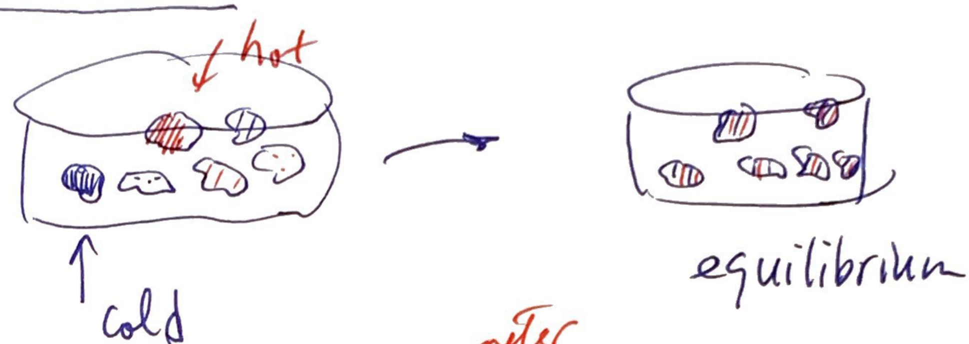
$$T_{eq} = 85.8\,°C$$

Looks like center of mass:



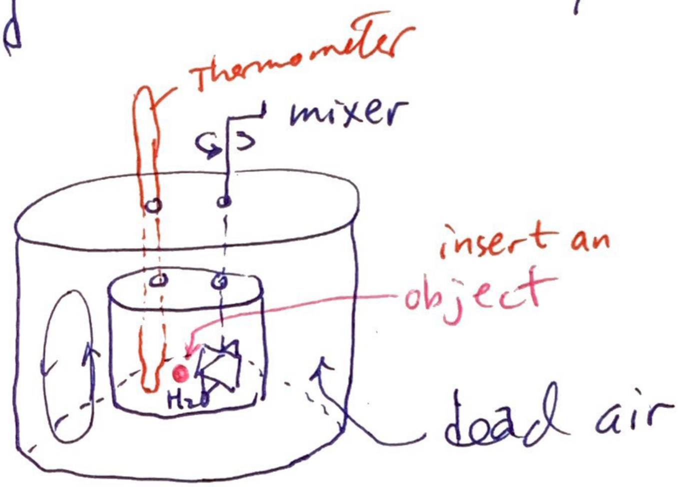
$$x_{cm} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

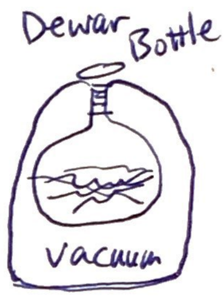
* Energy conservation is $\sum \Delta Q = 0$



* calorimeter

We have a befor and after scenario





- we watch the thermometer until we see no more change occuring ⇒ equilibrium.

EX We want to find "c" for an unknown substance. 0.150 kg of sample @ 540°C placed into 0.4 kg of water @ The container (interior) is 0.20 kg of Al @ 10°C. After we see motion of the thermometer cease, we record 30.5°C : Find "c"

eqn: $\sum \Delta Q = 0$: $m_{sample} c_{sample} (T_f - T_i) + m_w c_w (T_f - T_i) + m_{cal} c_{cal} (T_f - T_i) = 0$ (Find: c_{sample})

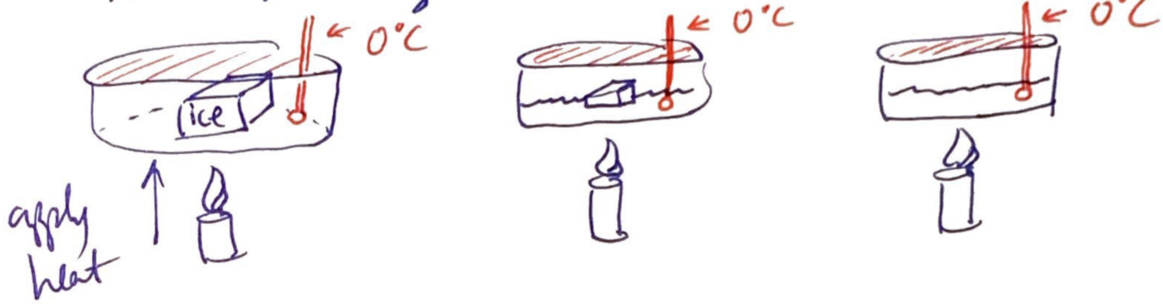
$$(0.15) c (30.5 - 540°) + (0.4)(4186 \tfrac{J}{kg°C})(30.5 - 10°) + (0.2)(900 \tfrac{J}{kg°C})(30.5 - 10°) = 0$$

$$-76.4 \cdot c + 34300\ J + 3690\ J = 0$$

So $c = \dfrac{-34300 - 3690}{-76.4} = \boxed{497\ J/kg°C}$

* Latent Heat of Fusion L_f

Consider melting a small block of ice.

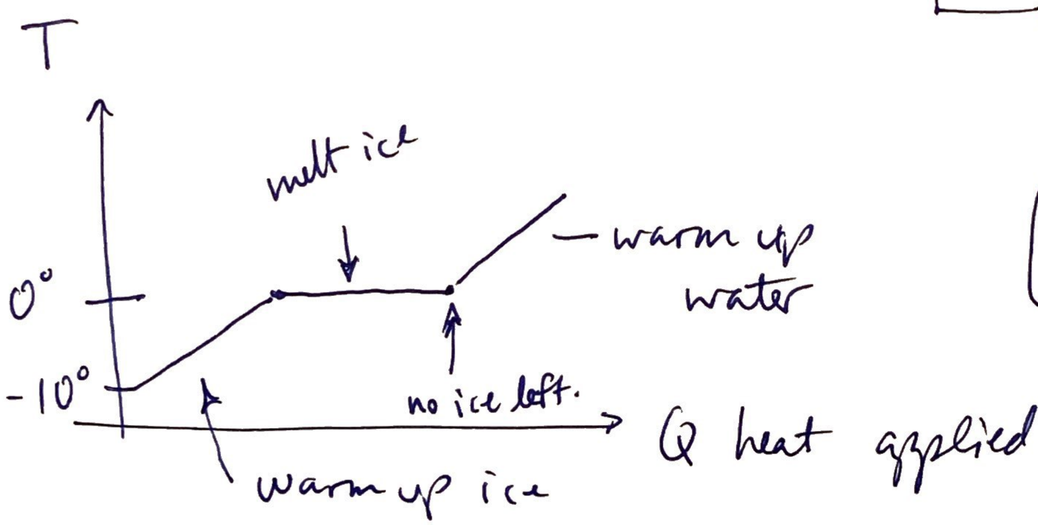


we see it take energy to melt the ice, but the surrounding water does not heat up until the last of the ice is melted.

- Energy is going into change the phase of H_2O from a solid to a liquid.
- we call this the "Latent heat of fusion"
- wether we melt or freeze, energy is used to change phase.

as long as we see ice we know the liquid is 0°C

- consider ice @ -10°C



H_2O:

$$L_f = 33\,\frac{kJ}{kg} = 8.0\,\frac{kcal}{kg}$$

EX How much heat is needed to melt 0.5 kg of silver if it is @ 100°C

Silver melts @ 961°C , $L_{f_{Ag}} = 88{,}000\ J/kg$

$C_{Ag} = 230 \frac{J}{kg\,°C}$

Q heat to warm Ag from 100°C to 961°C

$= m_{Ag}\, C_{Ag}\, \Delta T$

Q heat to melt Ag $= m_{Ag}\, L_{f_{Ag}}$ ← {no ΔT here}

Total

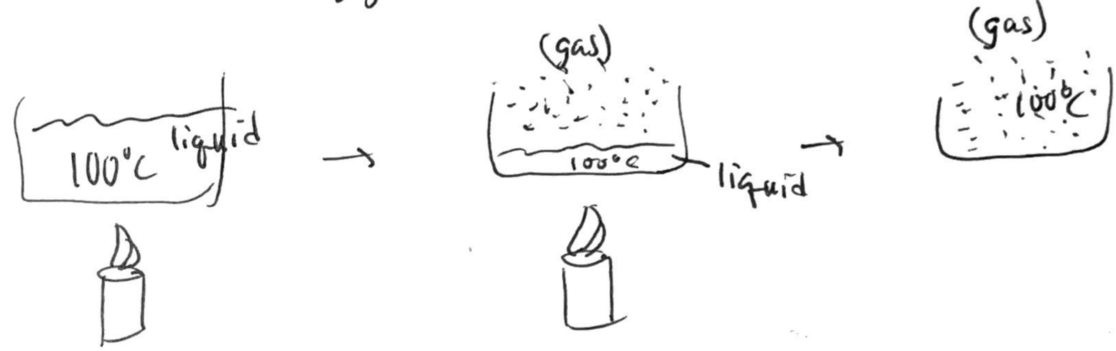
$Q_{TOT} = (0.5\,kg)(230\ J/kg°C)(961-100°C) + (0.5\,kg)(88{,}000\ J/kg)$

$= 99{,}015\ J + 44{,}000\ J$

$= 143{,}015\ J$ or **143 kJ**

* Latent heat of Vaporization

It take energy to boil water



The energy to change phase from a liquid to a gas is called the "latent heat of vaporization"

EX

$$L_{V_{H_2O}} = 22,600 \ J/kg$$ $= 539 \ kcal/kg$

EX