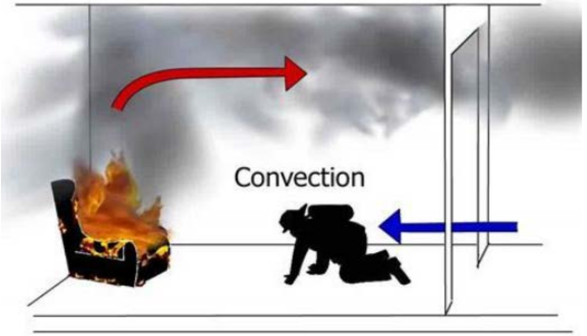
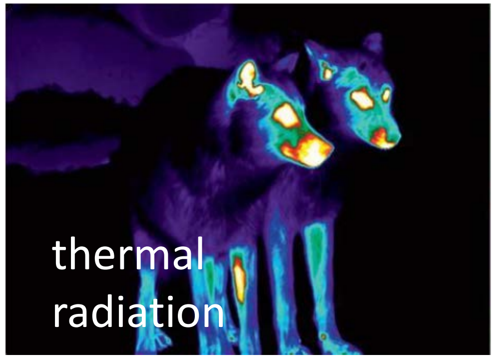
F.2 Energy Transfer Methods

Already discussed how to calculate the energy of an object. And now we have to consider how its energy can be changed, by having something transfer energy to our object, or having our object transfer energy elsewhere. There are two main processes:

Work

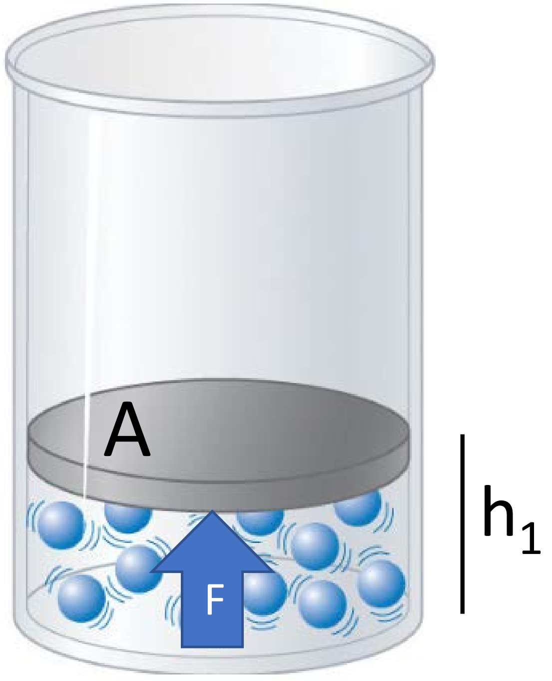
Heat

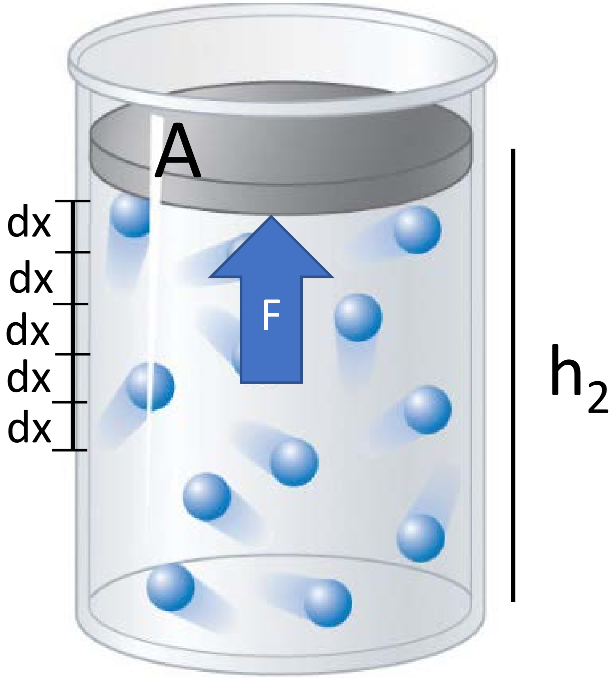




F.2 Work

Work (W) = Energy transfer accompanied by a *net* force.





When gas expands it does work on its container:

$$W = \int_{h_1}^{h_2} F dx$$

$$= \int_{h_1}^{h_2} PA dx$$

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

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

note V is volume here ($V_1 = Ah_1$, $V_2 = Ah_2$) and must be measured in m^3.

Gas exerts a force, F, on its container, via all the collisions it makes with it. Pressure it exerts is defined to be:

$$\text{Pressure: } P = \frac{Force}{Area} = \frac{F}{A}$$

$$\text{units: } \frac{\text{N}}{\text{m}^2} \equiv \text{Pascal (Pa)}$$

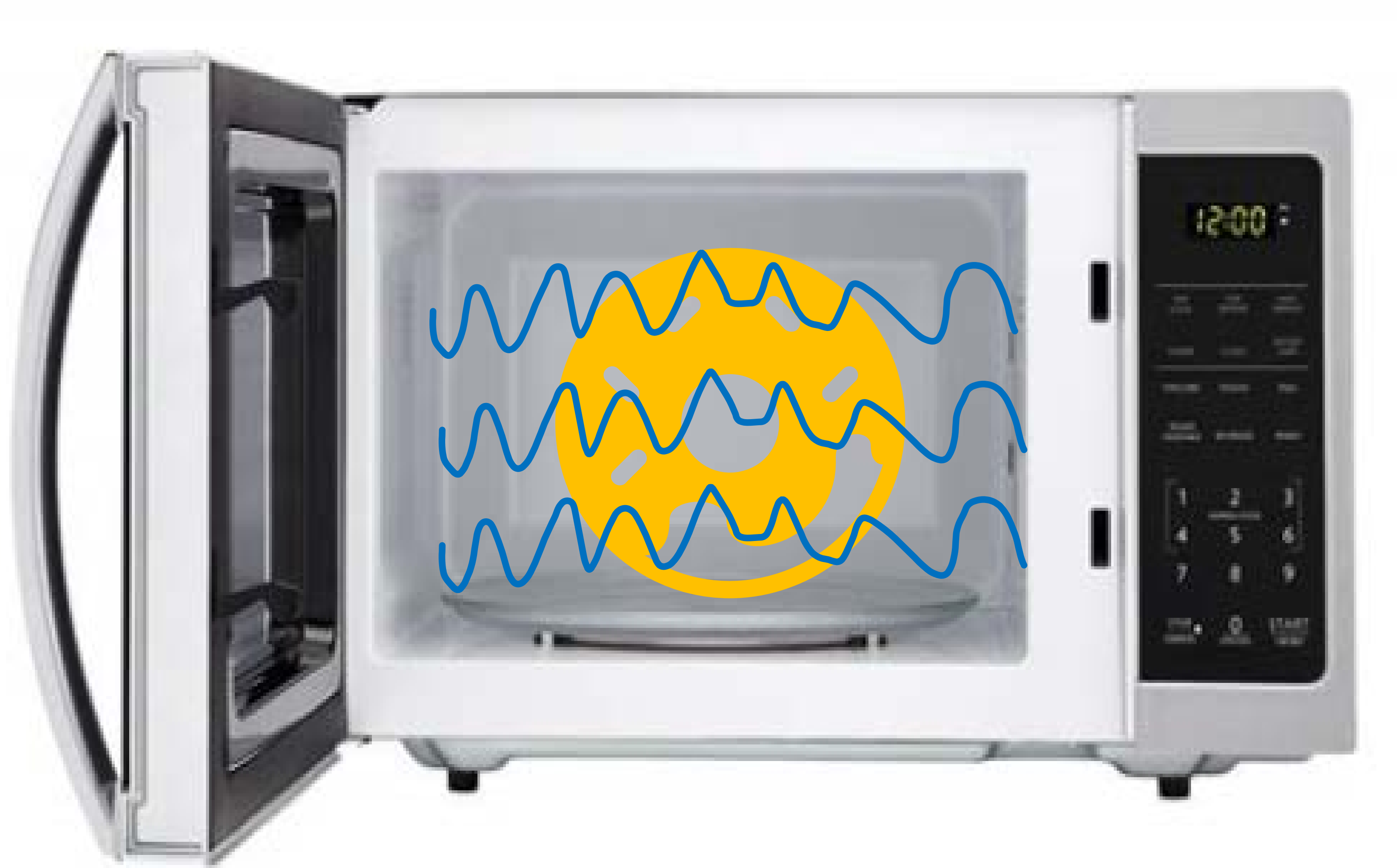
For instance, $P_{atmosphere}$ = 101320 Pa

F.2 Heat

Heat (Q) = Energy transfer accompanied by a zero *net* force.

e.g., in a microwave….

- it creates electromagnetic field waves permeating the donut.
- The electromagnetic field exerts forces on the charges in the atoms of the donut, doing work on them, and speeding them up (increasing T)
- but since the electromagnetic field wave is rapidly varying, its force points up just as much as down, and there is no *net* force.



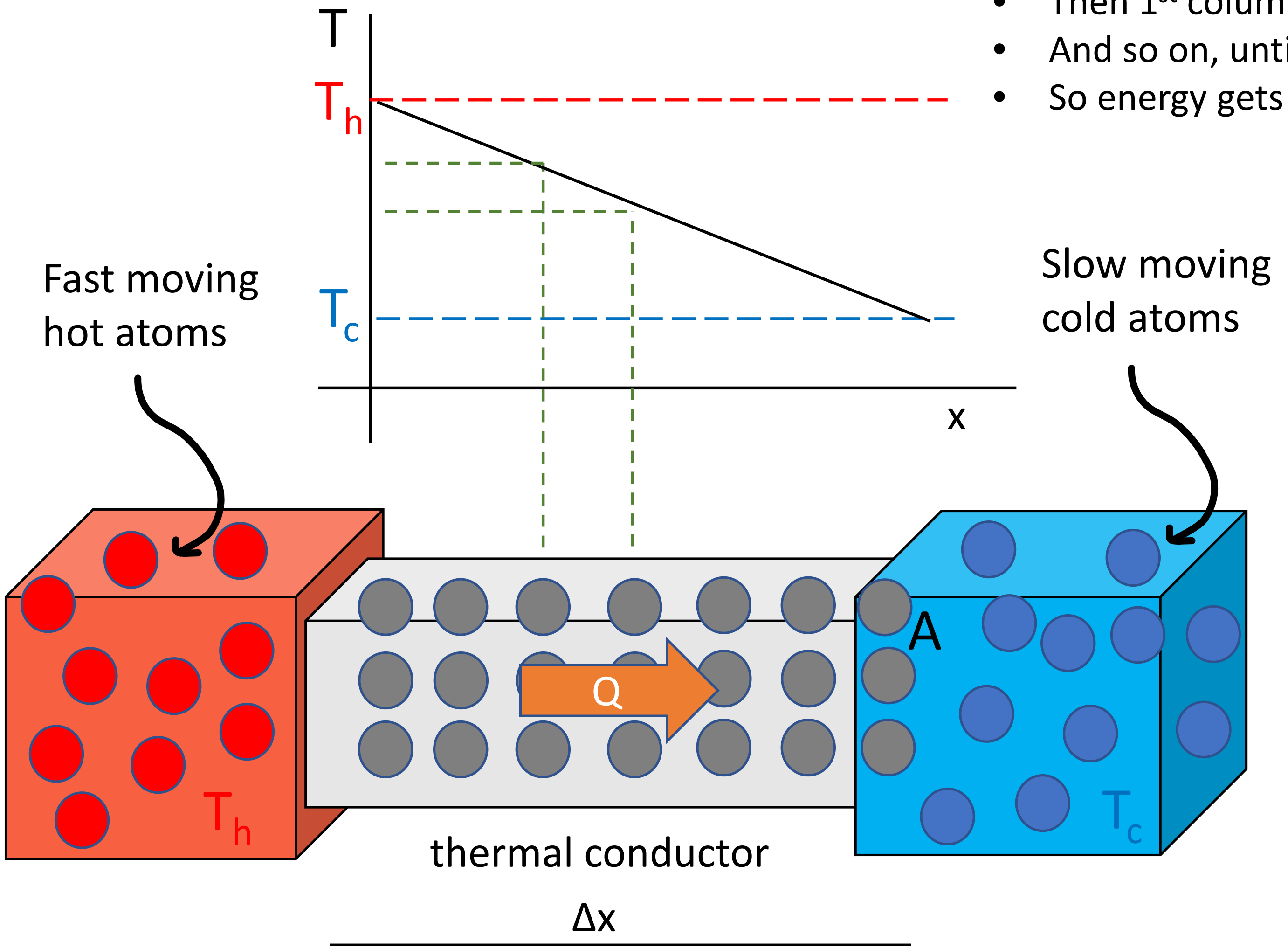
There are four main kinds of heat transfer, and each has an associated formula.

F.2 Heat (Conduction)

Conduction occurs by direct contact between atoms at different temperatures.

- Hot atoms collide with 1st column of thermal conductor atoms, raising their T.
- Then 1st column then collides with the 2nd column, raising *their* T,
- And so on, until the last column collides with the cold atoms, raising *their* T.
- So energy gets transferred from hot to cold. And rate of energy transfer is this:

$$\frac{dQ}{dt} = kA\frac{\Delta T}{\Delta x}$$



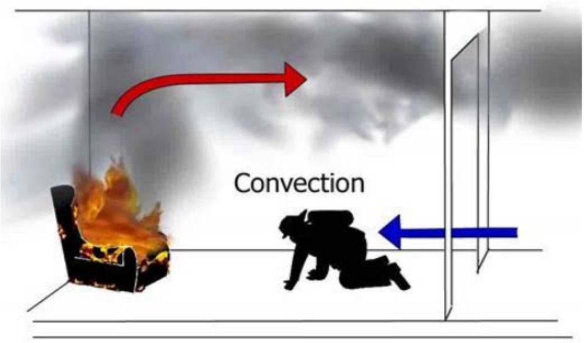
A = area of thermal contact between hot/cold atoms, and kind of models # atoms making collisions.

k = thermal conductivity (W/mK). Kind of measures frequency of collisions between atoms. e.g.,

$$k_{air} = 0.024\frac{W}{m \cdot K} \qquad k_{wood} = 0.17\frac{W}{m \cdot K}$$

$$k_{water} = 0.58\frac{W}{m \cdot K} \qquad k_{Ag} = 429\frac{W}{m \cdot K}$$

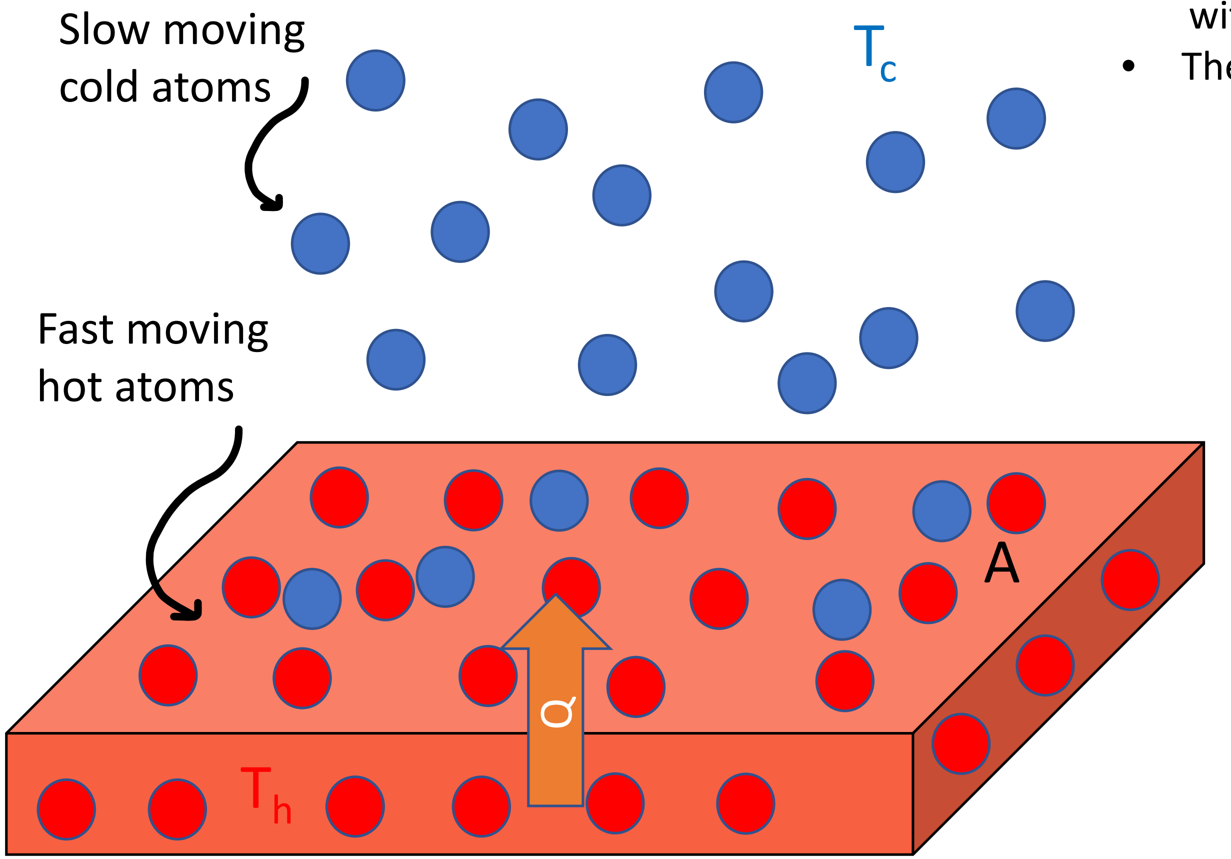
$\frac{\Delta T}{\Delta x}$ = thermal gradient (slope) and kind of models temp. difference between neighboring columns, and thus the amount of energy transferred per collision.



T

F.2 Heat (Convection)

Convection also occurs by direct contact between atoms at different temperatures, but at least one of the substances must be a fluidic medium.



- Hot atoms collide with cold atoms, making the cold atoms accelerate upward.
- Colder atoms descend and take their place, to be in turn heated by collisions with hot atoms and accelerated upwards.
- These upwardly moving atoms constitute the convection current.

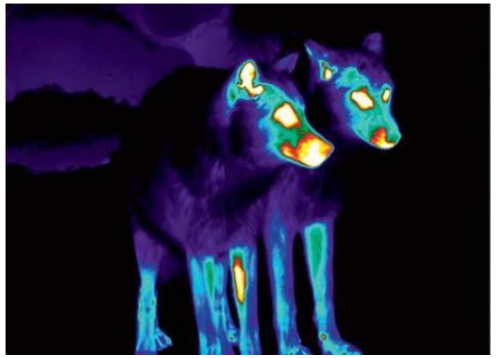
$$\frac{dQ}{dt} = hA\Delta T$$

A = area of thermal contact between hot/cold atoms, and kind of models # atoms making collisions.

h = thermal convection (W/m^{2}K). Kind of measures frequency of collisions between atoms, and the speed of the convection currents.

$$h_{air} \sim 10\frac{W}{m^2K}$$

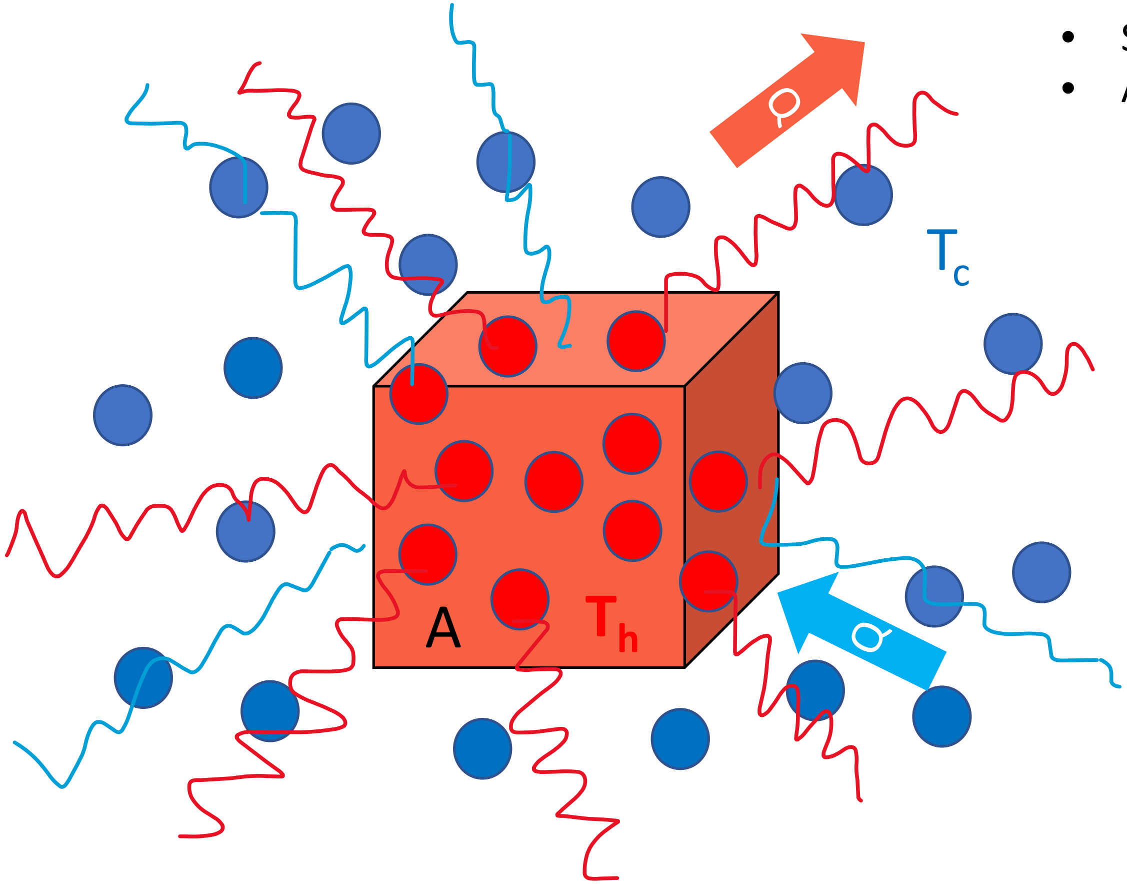
ΔT = is the temperature difference between neighboring hot and cold atoms, and thus the amount of energy transferred per collision.



F.2 Heat (Thermal Radiation)

Thermal radiation is the electromagnetic wave energy that atoms emit by virtue of their (charge's) thermal oscillations.

- Atoms in environment naturally are oscillating back and forth by virtue of their T.
- Moreover the charges inside the atoms are oscillating as well.
- Any oscillating charge emits electromagnetic waves (which carry energy).
- So substance will gain energy from environment this way.
- And it will itself radiate energy away into the environment in the same way.



$$\frac{dQ}{dt} = \sigma \varepsilon_{th} A(T_h^4 - T_c^4)$$

$$\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2\text{K}^4}$$

ε_{th} = thermal absorptivity, is the fraction of energy absorbed

A = area of thermal contact between hot/cold atoms,
and kind of models # atoms able to absorb/emit radiation.

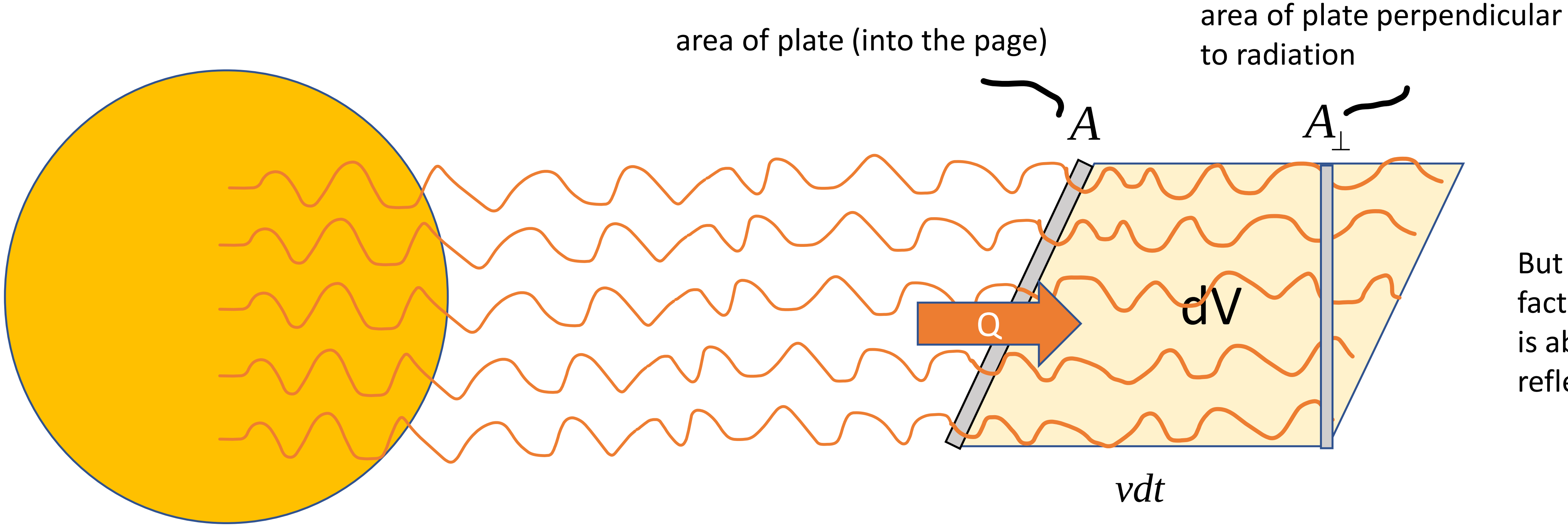
T^4 = amount of energy radiated by an atom at temperature T.

F.2 Heat (Solar Radiation)

Solar radiation is technically thermal radiation from the Sun.

Since solar radiation is thermal radiation, the previous formula applies to it as well, in a sense. The only difference is that this radiation is at a different temperature (around 5800K) than the environment, and that its headed in a particular *direction,* instead of coming from all sides. And so its prudent to develop a special formula for this case.

$$\frac{dQ}{dt} = \frac{udV}{dt} = \frac{uA_{\perp}vdt}{dt} = uvA_{\perp} = IA_{\perp}$$



But then have to account for fact that only a fraction ε_{sol}, is absorbed, and the rest reflected. So

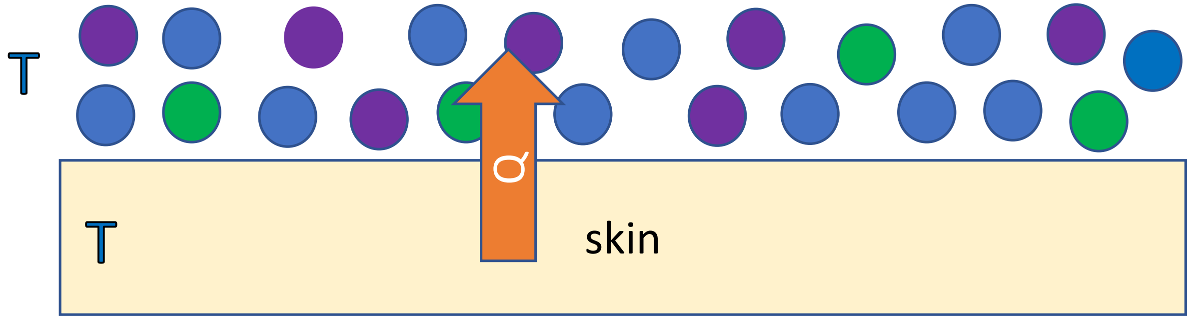
$$\frac{dQ}{dt} = \varepsilon_{sol} IA_{\perp}$$

F.2 Heat (Evaporation)

Evaporation is in a sense vaporization, one particle at a time

Water/sweat, and skin are at same T, and so their molecules are moving at the same average speed.

But these molecules, the water molecules in particular, are not all going at the *same* speed. Some move faster than average (green), and some slower (purple).



The faster moving water molecules can escape the liquid surface, if they're fast enough.

This brings the *average* speed of the water molecules down, and hence their T. Now the skin is at higher T and will conduct heat to the water.

Process repeats until all water is 'boiled' away.

$$\frac{dQ}{dt} = \frac{d(mL_v)}{dt} = \frac{dm}{dt}L_v \longrightarrow \frac{dQ}{dt} = \frac{dm}{dt}L_v$$

The rate of heat given off in this way is then the rate at which the water is being 'boiled' off, i.e., evaporated.