Heat (Temperature) Transfer

Temperature is transferred by the emission and absorption of photons by electron in atoms and molecules.

Photons are described by three parameters $(mass \,\&\, frequency \,\&\, radius)$.

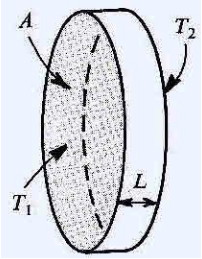
The higher the temperature, the higher the $(mass \,\&\, frequency)$ and the smaller the $(radius)$.

Absorption is always from a higher temperature to a lower temperature.

When two atoms are molecules collide:

- The atom or molecule with the highest temperature emits a photon.
- The atom or molecule with the lower temperature absorbs the photon.

As an example:



The material in the photo has thickness (L) and an area (A).
One face has temperature of (T_1) and the other face a temperature of (T_2).

$$(T_1 > T_2)$$

The quantity of heat transferred through the emission (ε) and absorption (α) of photons is:

$$\begin{bmatrix} \varepsilon\alpha = k(\Delta t)(A)(\frac{T_1 - T_2)}{L} \\ \frac{\varepsilon\alpha}{\Delta t} = k(A)(\frac{T_1 - T_2)}{L} \end{bmatrix}$$

Where (k) is a proportionality constant that depends on the nature of the substance.

The units of (k) are: $\left[\frac{(kg)(m/s^2)(m)/s}{mT} = \frac{(kg)(m/s^2)(m)}{smT}\right]$

All transfers of temperature use the same physical method. This physical method is the emission of photons by higher temperature atoms and molecules and the absorption of these photons by lower temperature atoms and molecules.

A *blackbody* is defined as a body that absorbs all the photons that impact the *blackbody*. At thermal equilibrium, a body continually emits the same photons that they absorb. This means that a good absorber of photons is also a good emitter of photons.

An equation developed by Stefan-Boltzmann shows that the total $(M\vec{a}d)$ of the photons emitted per second by a unit area of surface is proportional to the temperature of the surface raised to the fourth power. For a *blackbody*, the equation is: $\left[\frac{M\vec{a}d}{sm^2} = \sigma T^4\right]$.

Where $\left[\sigma = 5.67 < 8 \frac{(kg)(m/s^2)(m)/s}{m^2T}\right]$

Problems

1. An iron plate $(2cm = 0.02m)$ thick has a area of $(5000cm^2 = 0.5m^2)$. One side is at $(150^oC = 423^oT)$ and the other side is at $(140^oC = 413^oT)$. How much heat passes through the plate each second? For iron, $\left[k = 0.115\frac{cal/s}{(cm)(C^o)} = 48.1\frac{(kg)(m/s^2)(m)/s}{mT}\right]$

$$\left[\frac{\varepsilon\alpha}{\Delta t} = k(A)(\frac{T_1 - T_2)}{L} = (0.115\frac{cal/s}{(cm)(C^o)})(5000cm^2)(\frac{150^oC - 140^oC)}{2cm}) = 2875\,cal/s\right]$$

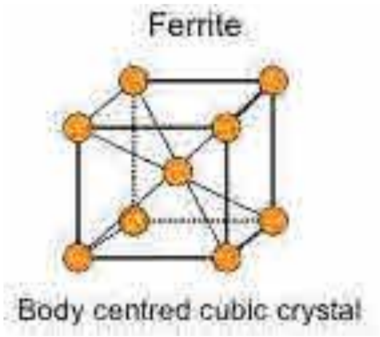
Convert to $\frac{(kg)(m/s^2)(m)/s}{mT}$

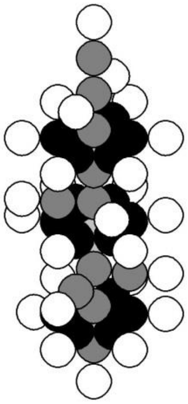
$$\left[(2875\,cal/s)(4.184(kg)(m/s^2)(m)/cal) = 12029(kg)(m/s^2)(m)/s\right]$$

$$\left[k = \frac{\varepsilon\alpha}{\Delta t}\frac{1}{A}\frac{L}{T_1 - T_2} = (12029(kg)(m/s^2)(m)/s)(\frac{1}{0.5m^2})(\frac{0.02m)}{10^oT}) = 48.1\frac{(kg)(m/s^2)(m)/s}{mT}\right]$$

$$\left[\frac{\varepsilon\alpha}{\Delta t} = k(A)(\frac{T_1 - T_2)}{L} = (48.1\frac{(kg)(m/s^2)(m)/s}{mT})(0.5m^2)(\frac{423^oT - 413^oT)}{0.02m}) = 12029(kg)(m/s^2)(m)/s\right]$$

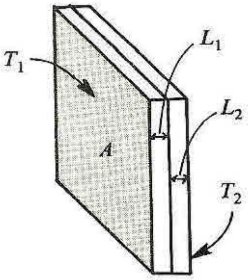
Iron the 26th element in a periodic table. The majority of iron atoms contain 26 protons 30 neutrons.





2. A metal plate $(4<3m)$ thick has a temperature difference of $(32^{o}C)$ between its faces. Through the emission of photons by electrons from the hotter side and the absorption of photons by the electrons on the colder side of the plate, $(2>5\,cal/h)$ move through a $(5cm^2=5<4m^2)$ area of the plate. Calculate (k) in $\left[\frac{(kg)(m/s^2)(m)/s}{mT}\right]$.

$$\left[\begin{array}{l} k=\frac{\varepsilon\alpha}{\Delta t}\frac{1}{A}\frac{L}{T_1-T_2}=\frac{(2>5\,cal/h)(4.184\,(kg)(m/s^2)(m)/cal)}{3600\,s/h})(\frac{1}{5<4m^2})(\frac{4<3m)}{32^{o}T}) \\ =58.5\frac{(kg)(m/s^2)(m)/s}{mT} \end{array}\right]$$



3. Two metal plates are soldered together. $(A = 80cm^2 = 0.008m^2)$
$(L_1 = L_2 = 3.0mm = 0.003m)$ $(T_1 = 100^oC = 373.15^oT)$
$(T_2 = 0^oC = 273.15^oT)$

For the left plate $\left[k_1 = 0.115\frac{cal/s}{(cm)(^oC)} = 48.1\frac{(kg)(m/s^2)(m)/s}{mT}\right]$

For the right plate

$$\left[k_2 = 0.163\frac{cal/s}{(cm)(^oC)} = (0.163)(419) = 68.3\frac{(kg)(m/s^2)(m)/s}{mT}\right]$$

Find:

1: The heat flowing through the plates (emission of photons by electrons from the hotter side and absorption of photons by electrons on the colder side).

2. The temperature (t) of the soldered junction.

A: (2): The heat flowing through plate 1 is equal that through plate 2.

The temperature (t) in the soldered junction will be:

$$\left[k_1A\frac{T_1 - t}{L_1} = k_2A\frac{t - T_2}{L_2}\right] \text{Since } (L_1 = L_2) \quad \left[\begin{array}{l} k_1A(T_1 - t) = k_2A(t - T) \\ = k_1(100^oC - t) = k_2(t - 0^oC) \end{array}\right]$$

solving for (t) $\left[(t) = (100^oC)\frac{k_1}{k_1 + k_2} = (100^oC)\frac{0.115}{0.115 + 0.163} = 41.4^oC\right]$

A: (1): The heat flowing through the plates will be:

$$\left[\frac{\varepsilon\alpha}{\Delta t_{time}} = k_1A\frac{T_1 - t_{temp}}{L_1} = (0.115\frac{cal/s}{(cm)(^oC)})(80cm^2)(\frac{(100 - 41.4)^oC}{0.30cm} = 1800\,cal/s\right]$$

Heat flowing through the plates in $\left[\frac{(kg)(m/s^2)(m)/s}{mT}\right]$ units.

$$\left[(1800\,cal/s)(4.184\,(kg)(m/s^2)(m)/cal) = 7531.2\,(kg)(m/s^2)(m)/s\right]$$

$$\left[k = \frac{\varepsilon\alpha}{\Delta t}\frac{1}{A}\frac{L}{t} = (7531.2\,(kg)(m/s^2)(m)/s)(\frac{1}{0.008m^2})(\frac{0.003m)}{41.4^oT}) = 68.3\frac{(kg)(m/s^2)(m)/s}{mT}\right]$$

$$\left[\begin{array}{l} \frac{\Delta\varepsilon\alpha}{\Delta t} = k(A)(\frac{t}{L}) = (68.3\frac{(kg)(m/s^2)(m)/s}{mT})(0.008m^2)(\frac{41.4^oT)}{0.003m}) \\ = 7531.2\,(kg)(m/s^2)(m)/s \end{array}\right]$$

$$\left[\frac{\varepsilon\alpha}{\Delta t_{time}} = k_1A\frac{T_1 - t_{temp}}{L_1} = (48.1)(0.008)(\frac{(100 - 41.4)^oT}{0.003m} = 7516.4\frac{(kg)(m/s^2)(m)/s}{mT}\right]$$

4. Dimensions of a copper tube:

$(length:\ 3m)\ [(1.5cm)\ \text{inside diameter}\quad (1.7cm)\ \text{outside diameter}]$

$$\left[k = 1.0\frac{cal/s}{cm^oC} = 419\frac{(kg)(m/s^2)(m)/s}{mT}\quad \text{For Copper}\right]$$

The copper tube runs through a container of circulating water.
The water at (20^oC) passes over the copper tube.
Steam at (100^oC) passes through the copper tube.

What is the heat flow rate $[\Delta\varepsilon\alpha/\Delta t]$ from the steam into the water?
How much steam is condensed each minute?

A: What is the heat flow rate $[\Delta\varepsilon\alpha/\Delta t]$ from the steam into the water?

$[2\pi r_{id}L = 2\pi(0.750cm)(300cm) \approx 1400cm^2]$ inside surface area “Ai”.

$[2\pi r_{od}L = 2\pi(0.850cm)(300cm) \approx 1600cm^2]$ outside surface area ”Ao”.

For the equation, “A” will be average of two:

$$[A = 1/2(1400cm^2 + 1600cm^2) = 1500cm^2]$$

For the equation, “L” will be estimated to be: $(0.100cm)$

$$\left[\frac{\varepsilon\alpha}{\Delta t} = k(A)(\frac{T_1 - T_2}{L}) = (1.0\frac{cal/s}{(cm)(C^o)})(1500cm^2)(\frac{100^oC - 20^oC)}{0.100cm}) = 1.2 > 6\,cal/s\right]$$

$$\left[\begin{array}{l}\frac{\varepsilon\alpha}{\Delta t} = k(A)(\frac{T_1 - T_2}{L}) = (419\frac{(kg)(m/s^2)(m)/s}{mT})(0.15m^2)(\frac{373^oT - 293^oT)}{0.001m}) \\ = 5.028 > 6\,(kg)(m/s^2)(m)/s\quad \text{math error, should be >8}\end{array}\right]$$

A: How much steam is condensed each minute?

In one minute (60 sec), the heat conducted from the tube is:
$[\varepsilon\alpha\Delta t = (1.2 > 6\,cal/s)(60s) = 72 > cal]$
From experiments, it has been shown that $(540cal)$ must be emitted from electrons to condense one gram of steam at 100^oC.
$\left[\text{Steam condense per min} = \frac{72 > 6cal}{540\,cal/g} = 13.3 > 4grams = 133kg\right]$ in practice, various factors would greatly reduce this theoretical value.

5. A spherical body of $(2cm = 0.02m)$ in diameter is maintained at

$$(600^o C = 873^o T).$$

If the sphere emits photons as if it were a black body, at what rate are the photons emitted?

A: Surface area of a sphere is $(A_{surface} = 4\pi r^2 = (12.566)(0.01m)^2 = 1.26 < 3m^2)$

$$A\sigma T^4 = (1.26 < 3m^2)(5.67 < 8\frac{(kg)(m/s^2)(m)/s}{mT})(873^o T)^4 = 41.4(kg)(m/s^2)(m)/s$$

UNITS:

1 calorie = 4.184 $(kg)(m/s^2)(m)$
1 (cal/sec)/(cm2 C/cm) = 419 W/m K
1 watt=joule/s = $(kg)(m/s^2)(m)/s$