Oxygen in Earth System

→ Atmospheric O_2 accounts for only a small fraction of the "free" oxygen in the Earth's system

// where is the rest ??

⇓

Much larger quantities of free oxygen are present in the form of oxidized minerals in the Sedimentary rocks & in the crust & upper mantle.

⇓ O_2 is hiding in mineral.

$Fe_2O_3 + O_2 \rightarrow Fe_3O_4$

↓ oxygen is present

Sources of free oxygen — Photosynthesis / Redox reaction in the Earth's mantal.

Fe_3O_4 → oxygen is there.

Photosynthesis

$$CO_2 + H_2O \longrightarrow O_2 + H_2CO$$

⇓ radiation is absorbed — 0.43 to 0.66

Redox reaction (FeO reacts with oxidation to for Fe_2O_3)

$$\underline{FeO} + O_2 \longrightarrow Fe_2O_3$$

lower level of oxidized mineral

Oxygen is present in the Fe_2O_3

in the Earth crust → Redox reaction

$$2FeO + H_2O \longrightarrow Fe_2O_3 + H_2$$ ↗ volcanism

↓ Ferrous oxide; ↓ steam; ↓ Ferric oxide

The current level of oxidation in Earth is explained by this Redox reaction.

If this has a redox reaction, we can get back the oxygen

Photosynthesis is insufficient to explain the present oxidation of the earth → we will see this through some worked examples

Mass of O_2 required to raise oxidation of Earth.
units 10^3 kg/m² avg over the surface of the earth.

Reservoir	Mass
Atm O_2 →	2.353
Oceans & Sediments →	31
Crust Fe^{3+} →	> 100
Crust CO_3 →	~ 100
~~Crust (other) → > 100~~	
Mantle Fe^{3+} →	> 1000

Some estimates based on some scientific arguments & measurements

Q? # Reconcile the mass of Oxygen in the atm in the preceding table with the Vol conc given in a composition table.

Soln Vol' con of O_2 → 20.9 % (From the composition table)

Mass conc of O_2 (gravimetric analysis) → $20.9 \times \frac{32}{\text{Mol. wt of air}}$

$= \frac{20.9 \times 32}{28.91}$ ← already estimated

$= 23.12\ \%$

consider the mass of the air (reconcile the mass of O_2 in the atm) $= 1.004 \times 10^4$ kg/m²

$= \frac{23.12}{100} \times 1.004 \times 10^4\ (\text{kg}/\text{m}^2)$

$= 2.353 \times 10^3$ kg/m² → reconciled

7. Using the data provided in the previous table (carbon reservoir), estimate the mass of Oxygen required to form carbonate deposites in the earth's crust.

(In-organic carbon in Sedimentary rock is 80,000 kg/m^2 → How much O_2 is required in getting for this 80,000 kg/m^2

Next question → how much O_2 is released from the photosynthesis. How are will you work it out

that is the proxy for the amt released during photosynthesis

[plants → decay → die
the proxy is organic carbon.
⇓
20,000 kg/m^2

if you findout the amt of O_2 which has been used

Soln for problem 12 → not a Stright away problem. Some fundamental chemistry is required.

Combining ①, ②, ③ & ⑤

$$H_2O + CO_2 + Ca^{2+} \longrightarrow CaCO_3 + \underline{2H^+}$$

this two hydrogen ions generated as a by-product of this reaction combine with single O ion to form water.

i.e $2H^+ + O^{2-} \longrightarrow H_2O$

Adding ① & ②

$$CO_2 + \cancel{H_2O} + \underline{Ca^{2+}} \longrightarrow CaCO_3 + \cancel{2H^+}$$ → calcium Carbonate

$$\cancel{2H^+} + O^{2-} \longrightarrow \cancel{H_2O}$$

$$Ca^{2+} + CO_2 + O^{2-} \longrightarrow \underline{CaCO_3}$$

One free oxygen atom is paired with a carbon atom in CO_2 & Besides in the earth crust as carbonate. Hence mass of oxygen required to form the carbonate reservoir is

$$80{,}000 \ (kg/m^2) \times \frac{16}{12}$$

$$\sim 100{,}000 \ \underline{kg/m^2}$$ → This is the basis for writing crust CO_3 in the the previous table

Next Problem :- Using the data provided in the Previous table, estimate the Oxygen liberated by photosynthesis over the lifetime of the earth.

Soln Proxy is the organic carbon in the carbon reservoir. for photosynthesis O_2 releasing.

Plant, respires, decay -s die. → finally form as a organic carbon in the crust. → 20,000 kg/m² if you findout the amt of O_2 which has been used to form this 20,000 kg/m², → that is the proxy for the amt released during photosynthesis

what is the eqn we need to use here??

$$\underline{CO_2} + H_2O \longrightarrow \underline{O_2} + \underline{H_2CO}$$

one ~~oxygen mol~~ with the burial of each Carbon atom, one O_2 molecule is released.

hence Mass of oxygen liberated by the photosynthesis is

$$20{,}000\ kg/m^2 \times \frac{32}{12}$$

$$= \underline{53{,}000\ kg/m^2}$$

We got from in-organic CO_3 → 100,000 kg/m²
not matching
& from photosynthesis → 53,000 kg/m²

" Additional mechanism is required to the oxidation of the Earth" → which is through the redox reaction.

The principle ~~source~~ of free

completed the Introduction part → quiz portion

For a black doby $\underline{I_\lambda}$ or L, we can call as $\underset{\downarrow}{B_\lambda(T)}$

Absorbtion.

Emissive power of the black body. reflection, absorption for anything

$$E_b(T) = \int_0^\infty \pi B_\lambda(T)\, d\lambda$$

solid angle, Sr, $\frac{W}{m^2 \cdot \mu m \cdot sr}$, μm

What is that B_λ for all temp tend to 0, when $t \to 0$, tend to ∞, when $t \to \infty$ tend to 0, $\lambda \to 0$ & tend to ∞, $\lambda \to 0$. which is a great puzzle. max Plank came with expression in 1901 → Planck's law. then he figured out for this to be true, $E = h\nu$.

Black body :-

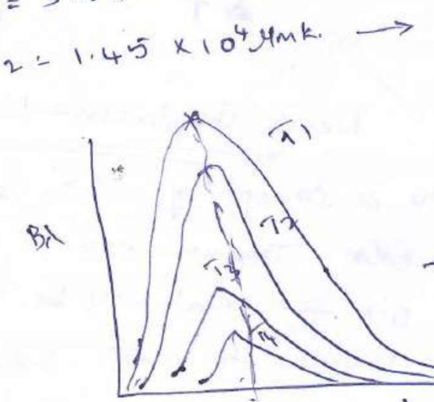
Black body :- is one which absorb all incident radiation regardless of its direction & wavelength.

$$B_\lambda(T) = \frac{C_1 \lambda^{-5}}{\pi\left[e^{\frac{C_2}{\lambda T}} - 1\right]}$$

→ planck's distribution

$C_1 = 3.74 \times 10^{-16}\ W/m^2$ → First radiation const

$C_2 = 1.45 \times 10^4\ \mu m K$ → Second radiation const



$T_1 > T_2 > T_3 > T_4$

Featury of the planck distribution

① $B_\lambda(T)$ Continiously varies with λ for every T "not a discontinious fn"

② For every temp there is a peak value of $B\lambda$

③ This maximum ~~shift~~ with temperature

④ At a given λ, B_λ increases with temperature.
(No two curves for two different temp intersect with each other).

Now: $\dfrac{\partial B_\lambda(T)}{\partial \lambda} = 0$ & Solving we get

$$= \frac{(-1)\,5\,\lambda^{-6}}{\left[e^{\frac{c_2}{\lambda T}} - 1\right]} + \frac{(-1)\,\lambda^{5} \cdot e^{\frac{c_2}{\lambda T}}}{\left[e^{c_2/\lambda T} - 1\right]^{2}} \cdot \frac{(-c_2)}{\lambda^{2} T}$$

$$\frac{5\,\lambda^{6}}{\left[\cancel{e^{\frac{c_2}{\lambda T}} - 1}\right]} = \frac{\lambda^{-5} \cdot e^{\frac{c_2}{\lambda T}}}{\left[\cancel{e^{\frac{c_2}{\lambda T}} - 1}\right]^{2}} \cdot \frac{c_2}{\lambda^{2} T}$$

If you re-arrange this eq:

$$\lambda_m = \frac{2897}{T} \quad \text{— ⑤}$$

Wein's displacement law.

This also leads us to a concept of color. Today I am wearing blue color: Trouser. 0.6 μm is the λ. If you put 0.4 → what will be the temp. 6000K. What will happen to me? What is color then.

The color u see is not emission, rather it is ~~emission~~. reflection.
It absorbs all the color, but it reflects blue color.
Real emission color → heat the iron piece. It will be orange color. → it is an emission color.
If nothing is coming out → Black. (Absence of color).
If it has to radiatly black, for 0 to 400 λ it has to absorb all the radiation. Radiatively black will be
Visibly black object.

\# Use Wein's displacement law compute the color of temperature of the sun for which the λ for the maximum solar emission to be ~~0.475~~ μm. 0.5 μm

$$\lambda_{max} T = 2898$$

$$\cancel{0.475}\ 0.5\ (T)_{sun} = 2898$$

Same for the earth is ($T_E = 288K$) $\lambda_{max} = 10.1\ \mu m$

$$T_{sun} = \cancel{6100K}\ 5790 \approx 5800K$$

Derivation of Steffen-boltzman law from planks distribution

$$E_b(T) = \int_0^\infty \pi B_\lambda(T)\, d\lambda$$

↳ Black body emissive power @ temp (T).

$$E_b(T) = \int_{\lambda=0}^{\infty} \frac{\cancel{\pi}\ C_1 \lambda^{-5}}{\cancel{\pi}\left[e^{\frac{C_2}{\lambda T}} - 1\right]} \quad — (i)$$

let $\frac{c_2}{\lambda T} = \eta$

$$-\frac{c_2}{\lambda^2 T}\, d\lambda = d\eta.$$

$$\therefore \quad E_b(T) = \int_{\infty}^{0} \frac{-c_1 \lambda^5}{[e^{\eta}-1]} \cdot \frac{\lambda^2 T}{c_2}\, d\eta.$$

The area under the curve remains the same, but it's labelled as negative.

$$E_b(T) = \int_0^{\infty} \frac{C_1}{C_2 \lambda^3} \frac{T}{[e^{\eta}-1]}\, d\eta$$

$$= \int_0^{\infty} \frac{C_1 T \, d\eta}{C_2 \left[\frac{C_2}{\eta T}\right]^3 [e^{\eta}-1]}$$

$$= \int_0^{\infty} \frac{C_1}{C_2^4} \frac{T^4 \eta^3}{[e^{\eta}-1]}\, d\eta \quad \text{—} (2)$$

$$= \frac{C_1 T^4}{C_2^4} \int_0^{\infty} \frac{\eta^3}{[e^{\eta}-1]}\, d\eta.$$

Very difficult to integrate. But you can numerically Integrate. But it will give the result of $\frac{\pi^4}{15}$.

$$E_b(T) = \left(\frac{C_1}{C_2^4} \frac{\pi^4}{15}\right) T^4$$

$$\left[\frac{3.74\times10 \times (3.14)^4}{15\times(1.438\times10^{-2})^4}\right] T^4$$

$E_b(T) = \sigma T^4$ where $\sigma = 5.67\times10^{-8}\ \frac{W}{m^2K^4}$

Calculate the equivalent black body Temp (T_E) of the solar photosphere (outermost visible layer of the Sun) based on the following information.

→ The flux density of solar radiation reaching the earth = $F_s = 1368\ W/m^2$

→ The earth - Sun distance 'd' is 1.5×10^{11} m.

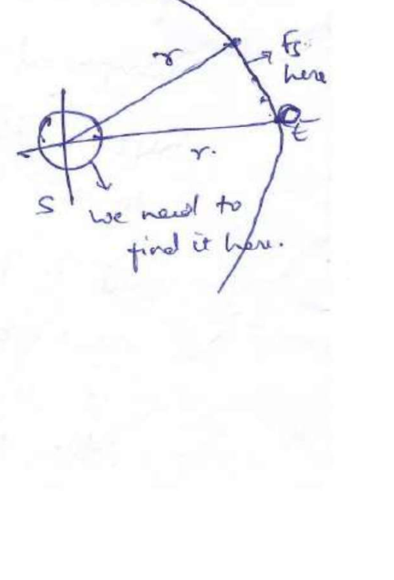
→ R_s of the Solar photosphere (radius of the Sun → $\underline{7.\times10^{8}\ m}$

If you have the flux density at the photosphere, using σT^4 you could estimate the $\underline{\text{temp}}$.

We know the F_s @ far distance, we need to get this for the photosphere. How are we going to do?

Using inverse square $\underline{\text{law}}$.

$$\boxed{F_s \propto \frac{1}{r^2}}$$



$$F_{photosphere} \propto \frac{1}{r_s^2}$$

$$F_s \propto \frac{1}{d^2}$$

$$\frac{F_{photosphere}}{F_s} = \left(\frac{d}{R_s}\right)^2 \text{ or } \left(\frac{R_s}{d}\right)^{-2}$$

$$F_{photosphere} = 1368 \left(\frac{7\times10^{8}}{1.5\times10^{11}}\right)^{-2}$$

$$= 6.28\times10^{7}\ \omega/m^2$$

But $\sigma T_s^4 = F_{photo}$

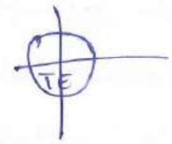
$$T_s = \left[\frac{6.28\times10^{7}\ (\omega/\cancel{m^2})}{5.67\times10^{-8}\ (\omega/\cancel{m^2}K^4)}\right]^{1/4}$$

$$T_s = \underline{5769\,K} \approx \underline{\underline{5800\,K}}$$

A Small blackbody Satellite is orbiting the Earth at a distance far enough away so that the flux density of Earth radiation is negligible, compared to that of Solar radiation. Suppose that the satellite suddenly passes into the Earth's Shadow. At what rate will it initially cool? The Satellite has mass $m = 10^3$ kg & a specific heat $C = 10^3 J (kg/k)^{-1}$; it is spherical with a radius $r = 1$ m., & the temp is uniform over its surface

Sol^n Consideration of energy balance

Radiative equilibrium.



Under equilibrium : the rate of change of enthalpy = Incoming - outgoing

Enthalpy is a measure of the energy in a system & its change is a measure of the heat added or lost by the system

$$mc \frac{dT_E}{dt} = \text{Incoming - outgoing}$$

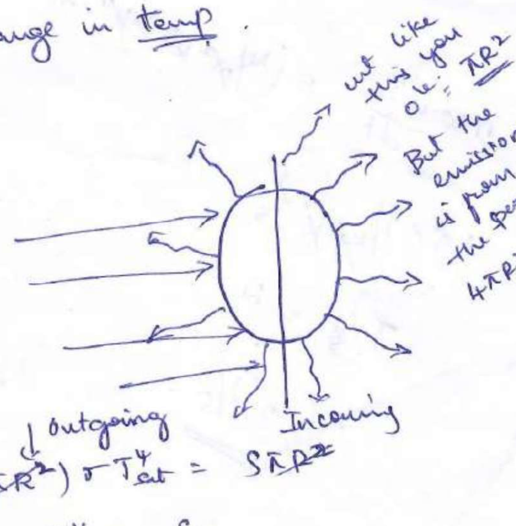
We need to find out $\frac{dT_E}{dt}$

or change in temp.

$F_E = \sigma T_E^4$

$T_E = \left(\frac{F_E}{\sigma}\right)^{1/4} =$

What is Fe ?



$$\text{Emission} \quad (4\pi R^2)\sigma T_{sat}^4 = S\pi R^2$$

$$T_{sat}^4 = \frac{S}{4\sigma}$$

$$T_{sat} = \left(\frac{S}{4\sigma}\right)^{1/4} = \left(\frac{1368}{4 \times 5.67 \times 10^{-8}}\right)^{1/4}$$

$$T_{sat} = 279K$$

When the Satellite passes into the Earth shadow, it will no longer be in radiative equilibrium. The flux density of solar radiation abruptly drop to zero while the emitted radiation, which is determined by the temperature of the satellite, drops gradually as the Satellite cools by emitting radiation.

$$\therefore \; mc\frac{dT_E}{dt} = \cancel{\text{Incoming}}^{0} - \text{outgoing}$$

$$mc\frac{dT_E}{dt} = -\text{Outgoing}$$

$$\therefore \frac{dT_E}{dt} = -\frac{(4\pi R^2)\,\sigma T_E^4}{mc} \qquad \frac{(W/m^2K^4)\,K^4 \times m^2}{J/K}$$

$$= -\frac{4315.086}{mc} \qquad \frac{K.W}{J.S}$$

$$mc\frac{dT_E}{dt} = (W/m^2K^4)\,K^4 \times m^2$$

$$kg \times J/kg.K \times K/s$$

$$J/s = W$$

$$J/s = J/s$$

$$\therefore \frac{dT_E}{dt} = -4.315 \times 10^{-3}\ K/s$$

$$kg \times 10^3 J/kg.K \cdot K/s$$

watts = watts

$J/s = W.$

$W.s = J$

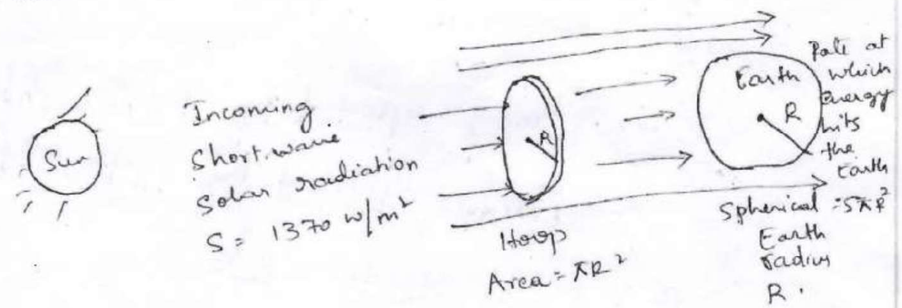
or 15.5 K/hr

A Simple Global temperature model

→ The Simplest Starting point for modeling climate begins with models that focus on factors influencing the single parameter temperature

→ Other factors such as precipitation patterns winds and storms & so forth are exceedingly important but they are more difficult to approach.

Simple climate mode → "Zero - dimensional Model" in which a single average global temperature is obtained that is not a funtion {Time, latitude, Longitude



The basic zero - dimensional energy balance model equates solar energy absorbed by the Earth with the energy that the Earth radiates back to space.

Radiation from the Sun arrives just outside the earth's atmosphere with an avg annual intensity, called the solar constant, $S = 1370\ w/m^2$

Rate of Solar energy Strikes the Earth

$= S\pi R^2$ (watts)

where S = Solar Const $= 1370 \; W/m^2$

R = Radius of the Earth (m)

Some of the incoming Solar energy that hits the Earth is reflected back into Space. → will not Contribute to their heating.

The fraction of incoming Solar radiation that is reflected is called the albedo → $\underline{\underline{31\%}}$

$\therefore$ Energy reflected by Earth $= S\pi R^2 \alpha$.

Energy absorbed by Earth $= S\pi R^2 (1-\alpha$

α = Earth albedo $= \underline{\underline{0.31}}$.

On the other hand, the earth radiates back the energy → in the form of radiation.

Every object radiates the energy at a rate $\propto$ to its Surface area $\times$ its absolute temperature raised to the 4^{th} power.

$$\underline{\underline{\propto 4\pi R^2 T_e^{\,4}}}$$

For this Model → Assume Earth as a black body.

Black body → it radiates as much as any object with the same temperature and area possibly can.

→ Also assume the earth is an isothermal

∴ Energy radiated back to the space by Earth $= \sigma 4 \pi R^2 T_e^4$

where σ = Stefan - Boltzmann Const $= 5.67 \times 10^{-8}$ $\underline{W m^{-2} K^{-4}}$

and T_e = earth's "effective black body" temperature $\underline{(K)}$

@ Steady State
Rate of energy from Sun absorbed =

Rate of energy emitted/ radiated back to the space.

$$S \pi R^2 (1-\alpha) = \sigma 4 \pi R^2 T_e^4$$

Solving for T_e

$$T_e = \left[\frac{S(1-\alpha)}{4\sigma} \right]^{1/4}$$

Substituting $S = 1370 \ W/m^2$, $\alpha = 0.31$ &
$\sigma = 5.67 \times 10^{-8} \ W/m^2 K^4$

We get

$$T_e = \left[\frac{1370\ W/m^2\ (1-0.31)}{4 \times 5.67\times10^{-8}\ W/m^2K^4}\right]^{1/4}$$

$$T_e = 254\ K = \underline{\underline{-19°C}} \quad \text{—— ①}$$

But the average temperature is $\underline{15°C}$

what is wrong here ??

that means Earth is $\underline{\underline{34°C}}$ more warmer.

The Greenhouse effect

Wien's displacement rule gives the λ at which a blackbody spectrum peaks as a function of its absolute temperature

$$\lambda_{max}(\mu m) = \frac{2898}{T(K)}$$