A brief Survey of the Earth's Atmosphere

Weight of unit volume of air

$$F = \rho g \quad \cdots \text{①}$$

Weight of air exerts downward force,

$$F = \rho g \quad \cdots \text{①}$$

Atmospheric Pressure, F/ Unit area

$$P_s = \int_0^\infty \rho g \, dz \quad \cdots \text{②}$$

$$P_s = Mg_0 \quad \cdots \text{③}$$

where, $$m = \int_0^\infty \rho \, dz \quad \cdots \text{④}$$

Problem 1: If the globally average surface pressure is 9.85×10^4 Pa & radius of the earth is 6.37×10^6 m. Estimate the mass of the earth.

Data, $P_0 = 9.85 \times 10^4$ Pa

Solu :- Part A: $P_s = mg_0$ $\quad (1 \text{ Pa} = 1 \text{ kg/ms}^2)$

$$9.85 \times 10^4 \, (\text{kg/m-s}^2) = m \times 9.81 \, (\text{m/s}^2)$$

$$\Rightarrow m = 1.004 \times 10^4 \, \frac{\text{kg}}{\text{m}^2}$$

Part B:

Mass of the atmosphere

M x Area

Area $= 4\pi R_E^2$

Mass $= 1.004 \times 10^4 \times 4 \times \pi \times (6.37 \times 10^6)^2$

$= 5.12 \times 10^{18}$ kg → Amount of air above us

Chemical Composition of Earth Atmosphere :-

What can you read b/w the lines?

Constituent	Molecular Wt. (g/mol)	Conc. by volume
N_2	28	78.1
O_2	32	20.9
Ar	40	0.9
H_2O	18	0-5%
CO_2	44	380 ppm
He	4	18 ppm
CH_4	16	1.75 ppm
H_2O	2	0.5 ppm
N_2O	44	0.3 ppm
O_3	48	0.01 ppm

$\Sigma = 99.9$ → The Earth is dominated by diatomic molecules

Trace gases

O → GHGs (green house gases)

→ Dry Air composition

Problem 2: Based on the chemical composition of the Earth atmosphere in given table, determine the molecular weight of atmospheric air.

Hint: You may choose to drop irrelevant gases

Soln:- Mol wt $= (28 \times 0.781) + (32 \times 0.209) + (40 \times 0.009)$

$= 28.92$ g/mol

Problem3 : Convert the volumetric analysis of the chemical composition of the earth's atmosphere to the gravimetric analysis (Instead of volumetric basis you need to estimate mass basis)

⇒ what is the first step to estimate the gravimetric analysis → You have to get the molecular wt.

Soln :- Gravimetric analysis

$$N_2 \rightarrow \frac{28}{28.92} \times 78.1 = 75.61\%$$

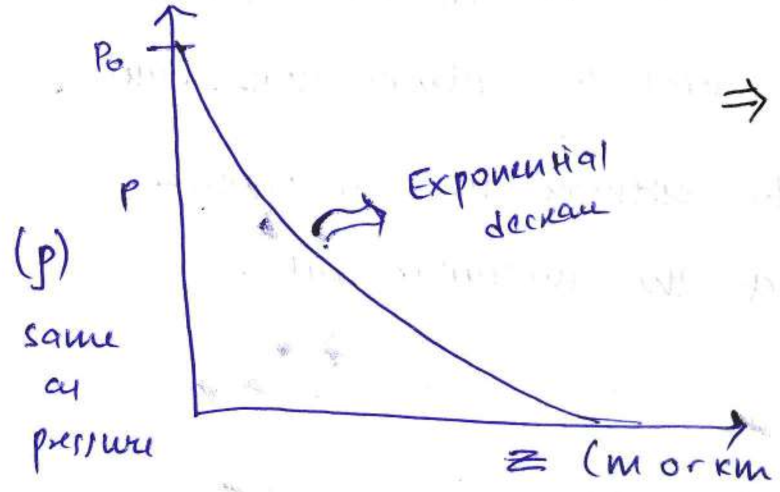
$$O_2 \rightarrow \frac{32}{28.92} \times 20.9 = 23.12\%$$

$$Ar \rightarrow \frac{40}{28.92} \times 0.9 = 1.24\%$$

$$\Sigma = 99.975\%$$

21% becomes 23% by weight because O_2 has a molecular wt. of 32 whereas the N_2 has a molecular wt. of 28.

Vertical Structure of Earth's Atmosphere :-



$$\Rightarrow \quad \rho = \rho_0 e^{-z/H}$$

$$P = P_0 \, e^{-z/H} \quad \ldots \text{(5)}$$

Pressure decreases exponentially with depth

$H \rightarrow$ e- folding depth

e - folding depth is the depth (height) at which the atmospheric pressure reduces to 36% ≃ 1/3 of the pressure at $z = 0$ / at the surface

When $z = H$

$$P = P_0 e^{-1}$$

$$P = \frac{P_0}{e} \quad \ldots \text{(6)}$$

$$P = 0.36 \, P_0 \quad \ldots \text{(7)}$$

$\therefore$ $H \rightarrow$ Scale height
≃ 8400 m for Earth

$H \rightarrow$ km

Problem 4 : At what height above sea level $(z_{1/2})$ does half of the mass of atm lies above & lies below. Assume H to be 8.5 km & $g = 9.81 \ m/s^2$ throughout.

$$P = P_0 \, e^{-z/H}$$

$$\frac{P}{P_0} = e^{-z/H} \quad \ldots \ldots \text{(8)}$$

$$\boxed{\ln\left(\frac{P}{P_0}\right) = -z/H} \quad \ldots (9)$$

} Pressure is a proxy of the mass

∴ we can take $\ln(0.5)$

$$\ln(0.5) = \frac{-z_{1/2}}{8.5}$$

$$z_{1/2} = 5.9 \text{ km}$$

How 0.5 ??

$P = mg \qquad \frac{0.5\,\cancel{mg}}{\cancel{mg}}$

$P_1 = mg$

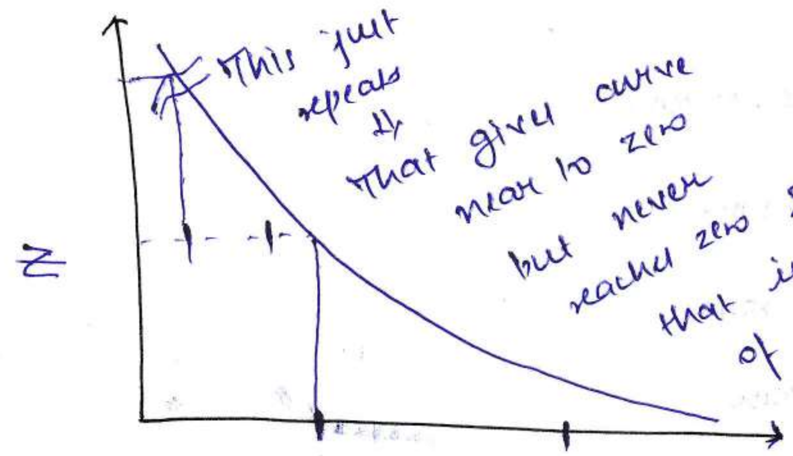
$P_2 = (0.5\,mg)$

∴ Total mass $= 5.11 \times 10^{18}$ kg

∴ 2.56×10^{18} present in the first 5.9 km & rest 5.9 km to ∞

∴ Atmosphere is very dense in first few km.

Civil Aircraft → 12 km



$H = \frac{RT}{Mg} = 8400$ m

M = molecular wt of atm air

There is no such thing called as top of atm because small amount of particle lies.

M = Mean mass of the one mole of the atm particle = 0.029 kg/mol for earth

R = Gas constant for the gas in question → specific gas constant

T ⇒ Temperature of the atmosphere] → single value ≈ bit of approximation
→ surface temp

g ⇒ surface gravity → Different for different planet

If H is large ≈ atm decreases its density slowly ≈ deeper atm

Smaller H ≈ shallow atm = thin atm

H for earth is ≈ 8.5 km, estimate it

$$H = \frac{RT}{Mg}$$

R → J/ kmol $= 8.314 \ kg\,m^2\,s^{-2}\,K^{-1}\,mol^{-1}$

$1\,J = 1\,kg\,m^2/\cancel{m^2}\,s^2$

$g = 9.8\ m/s^2$

$T = 290\ K$

$M = 0.029\ kg/mol$

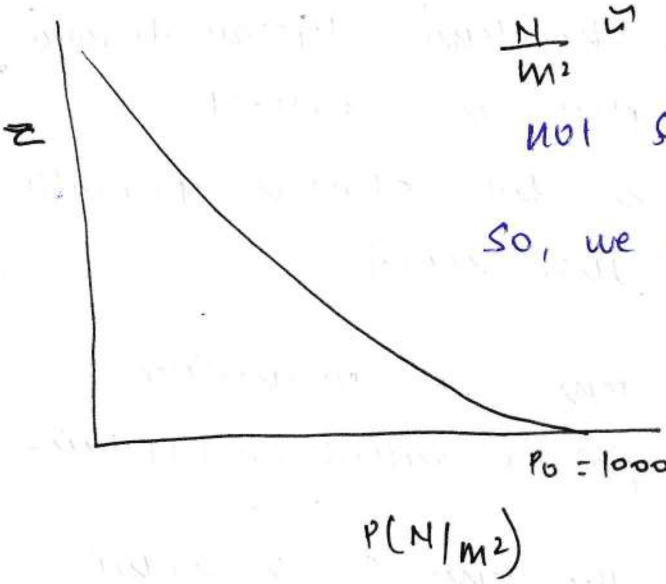
Solving

H ≈ 8500 m , 8.5 km

Venus = 15.9 km

Mars = 11.1 km

Jupiter = 27 km



$\frac{N}{m^2}$ ≈ is a very small no. which is not suitable for earth pressure representation

⇓

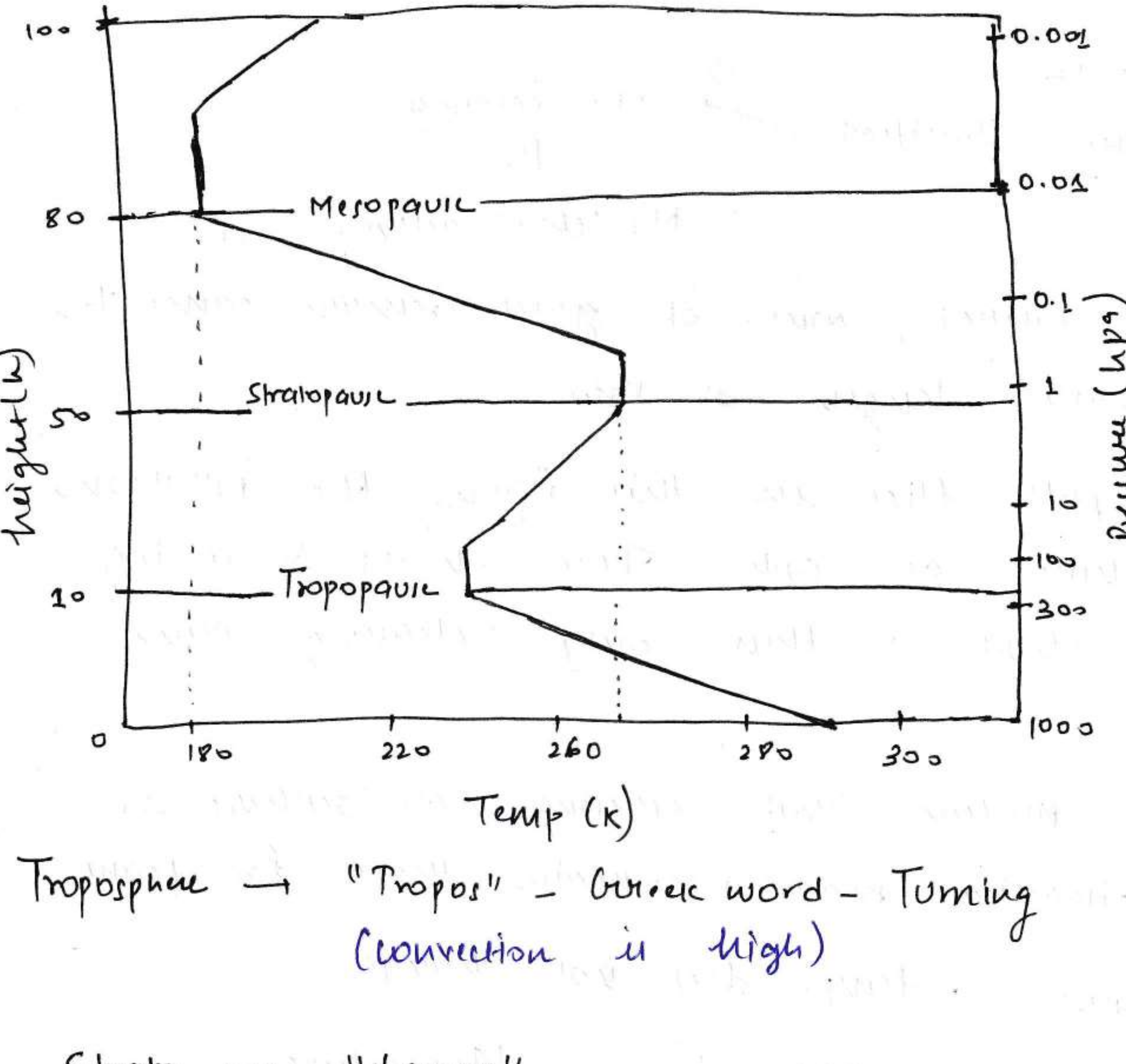
So, we need to represent with other units

i.e. hpa ≈ 100 pa

Therefore, 1 atm = 1000 hpa

Another unit millibar = 1 hpa

Vertical Structure of Atmosphere :- (The standard Atmosphere)



Troposphere → "Tropos" - Greek word - Turning
(convection is high)

Strato → "Layer"

Meso → " Middle"

Thermo → "Hotter layer"

* Starting from 300 K at $z=0$, the temp linear decreases upto the height 10 km → The place is called Troposphere (e.g :- if you go to a hill station, you will feel colder temp because of this reason)

→ As you reach some 10 km, temp is insensitive to height → is a pause or gap → called tropopause

→ After crossing the tropopause, the temp ↑ & reaches a local maxima - Stratosphere

Stratosphere :-

* Gases are Stratified → No mixing
⇓
No cloud activity

∵ It is stratified, conc. of gases remain same for considerable length of time

→ If aircraft flies in this region, the pollution remain there as such. There should be a big convective cloud → then only cleaning can happen.

→ Imagine nuclear blast entering stratosphere → The radioactive material remain there for years.

→ Stratopause → temp. does not change

→ Upto 80 km temp ↓ → Mesosphere

→ Mesopause & then temp ↑ with height.

$z > 105$ km

→ Mean path b/w the molecules are greater than 1 m.

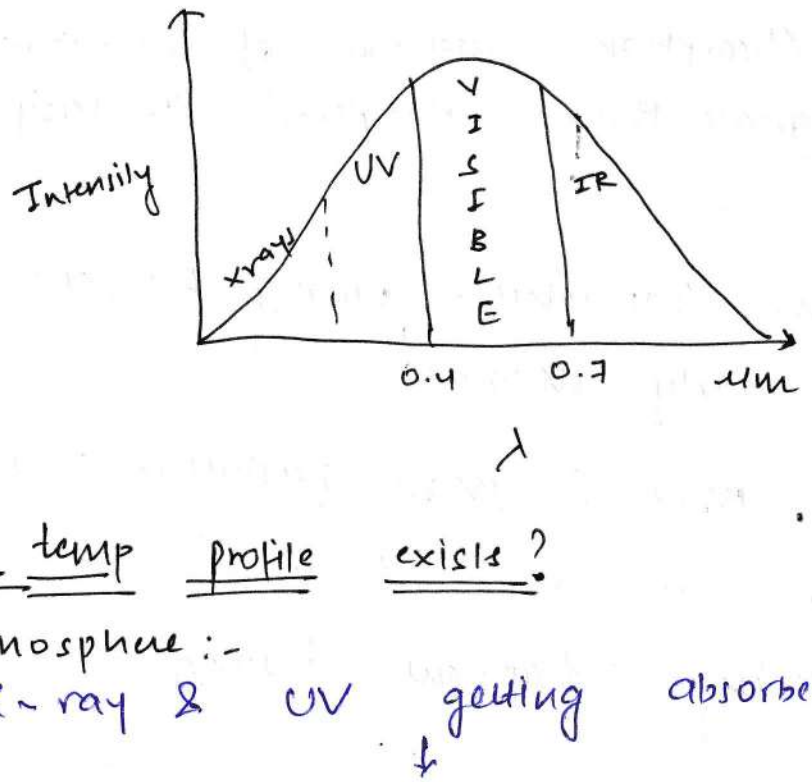
→ Individual molecules are sufficiently mobile making each gas behave as it existed alone.

The composition of gas which we studied will not be applicable after this altitude.

This layer is called Turbopause

Lighter species - H - may just escape out of earth atmosphere

Sun radiation



Why temp profile exists?

Thermosphere :-

* X-ray & UV getting absorbed by H_2 & He

↓

Photoionization process

↓

Release of Energy

Mesosphere :-

Less conc. of gas molecules

⇓

Absorption of solar radiation very less

⇓

So, temp decreases in mesosphere

Stratosphere :-

Presence of Ozone layer

↓

UV radiation gets absorbed

→ O_3 absorption happens, so temp increases in stratosphere

→ Absorption greater than emission

Troposphere :-

* Radiation cooling → Absorption - emission of radiation. Here, emission is greater than absorption. so, temp decreases.

* Temp Inversion in troposphere usually happens during night & early mornings.

* The earth emits more & more radiation back to the atmosphere as it cools down.

Even Reverse swing happens during this time.

$\frac{dT}{dz} = \Gamma$ = Lapse rate of atm or troposphere
$\simeq 6.67 \frac{K}{Km}$ i.e. temp decreases by 1°C for every 165 m

Troposphere is imp → as half of mass of atm lies.

Problem 5 # Determine fraction of mass of atm in troposphere.

Soln :- Using $P = P_0 e^{-z/H}$

We know, $m = \int_0^{10} \rho dz$ → In the troposphere

$$\text{Fraction} = \frac{m}{m_{total}} = \frac{\int_0^{10} \rho dz}{\int_0^{\infty} \rho dz}$$ → requires ideal gas eqn

$P_0 = 1000 \text{ hpa} \simeq 1 \times 10^5 \text{ pa}$

$P = 1 \times 10^5 e^{-10/8}$

$P = 28650 \text{ pa}$

$\therefore \frac{P}{P_0} = \frac{28.6}{100} = 28.6\%$.

$\therefore 1 - 28.6$

$= 71.4\%$.

Or, it can be solved by another method, which is given in next page.

$\underline{\underline{Sol^n}}$ w.k.T $M = \int_0^\infty \rho\, dz = 1.004 \times 10^4 \ kg/m^2$ — (1)

$$\therefore M_{Trop} = \int_0^{10} \rho\, dz$$

But $\rho = \rho_0 e^{-z/H}$ — (2)

Substituting (2) in (1)

$$M_{Trop} = \int_0^{10} \rho_0 e^{-z/H}.$$

Assuming $\underline{\rho_0 = 1.25 \ kg/m^3}$

We get

$$M_{Tro} = \rho_0 \int_0^{10} e^{-z/H}$$

$$= \rho_0 \left[\frac{e^{-z/H}}{[-1/H]} \right]_0^{10}$$

$$M_{Trop} = 1.25 \left[\frac{1 - e^{-10/8.5}}{1/8500} \right]$$

Solving, we get $M_{Trop} = 0.7 \times 10^4 \ kg/m^2$

$$\therefore \frac{M_{trop}}{M_{total}} = \frac{0.7 \times 10^4}{1.004 \times 10^4} \simeq 0.7 \simeq \underline{\underline{70\%}}$$

$\therefore$ 70% of the total mass is present in $\underline{\text{troposphere}}$

Atmospheric General Circulation

Any atmospheric flow used to refer to the general circulation of the Earth and regional movements of air around areas of high and low pressure. The reason we have global wind patterns is ultimately due to a differentially heated, rotating Earth. The differential heating of Earth continually causes an imbalance in air pressure and temperature around the world, which in turn causes a continuous general circulation of winds that attempt to restore balance. While actual winds in a given place and time may differ from the average general circulation, the average can provide an explanation for how and why the winds prevail from a particular direction in a certain place. The general circulation also serves as a model for how heat and momentum are transported from the equator to the poles.

Differential Heating

Because the Earth is round, solar radiation is not equally spread at all latitudes. Near the equator where sunlight shines directly on Earth, more solar radiation per square meter is received as compared to near the poles where sunlight shines at sharp angles to the surface (Figure 1). Toward Earth's poles, the same solar radiation is spread over a larger surface area such that each square meter of Earth's surface gets less radiation at the poles. As Earth rotates, the incoming solar radiation is zonally spread along latitude lines

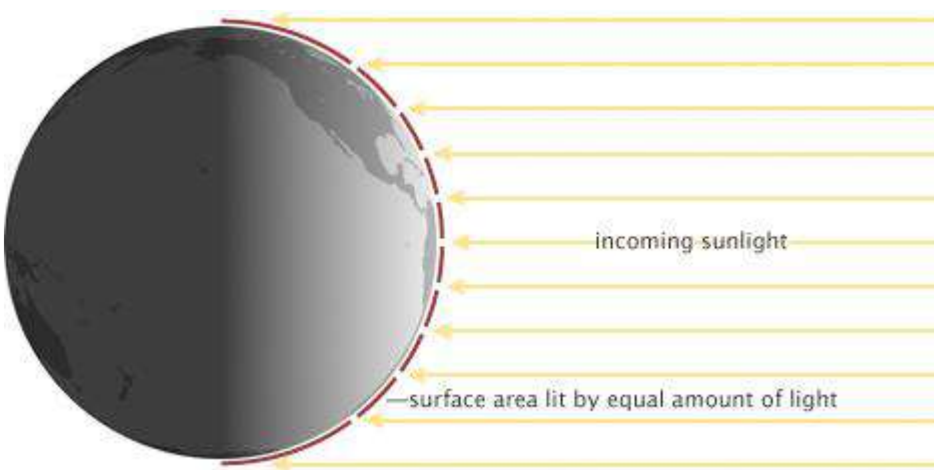


Figure 1: Earth's uneven heating by the sun due to the curvature of its surface

In this way, incoming solar radiation depends on latitude. The sun shines more directly on tropical regions at lower latitudes than at higher latitudes all year-round. Solar radiation adds heat to the Earth-atmosphere-ocean system, and thus lower latitudes get heated more than higher latitudes. This should be as expected because we know the tropics are warmer than the Polar Regions. While Earth is continually heated by the sun, it is also continually losing energy by emitting outgoing longwave infrared (IR) radiation at all latitudes, and at all times, both on the light and the dark side of the globe.

When averaged over the globe and over long time scales, incoming UV radiation exactly balances outgoing IR radiation. But, latitude by latitude, incoming UV and outgoing do not perfectly balance. More solar energy is received by the Earth in the tropics, and while the cooling by outgoing IR radiation helps to offset this, there is still a net gain of radiative energy in the tropics. However, near Earth's poles, incoming solar radiation is less direct and too weak to offset the cooling by outgoing IR radiation, so there is net cooling at the poles. This causes warmer air at the equator, and cold air at the poles and drives Earth's atmospheric general circulation (Figure 2).

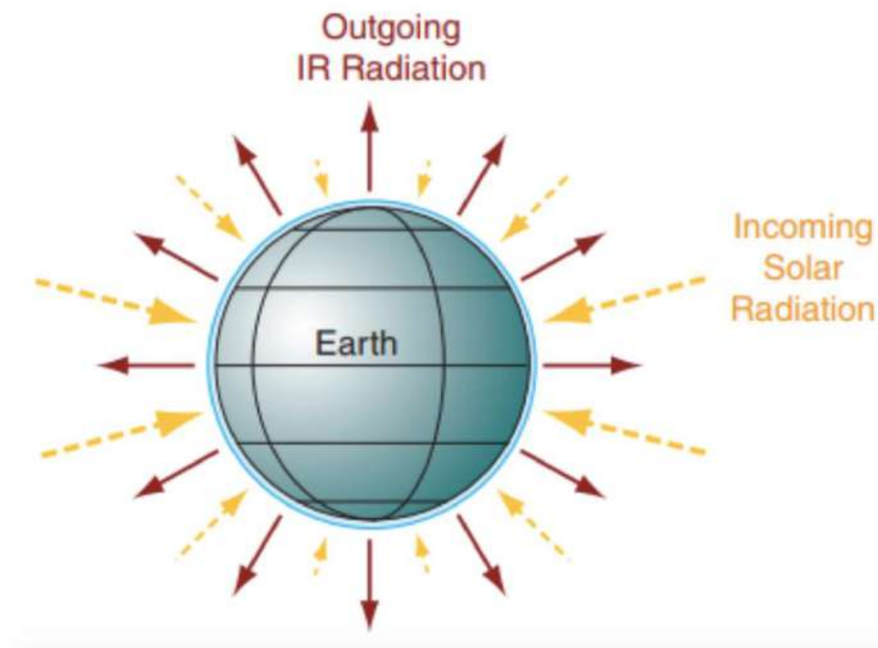


Figure 2: Incoming solar radiation (yellow dashed) and outgoing infrared radiation (red soild)

Earth's general circulation attempts to redistribute heat around the globe and rebalance the energy imbalances inherent in an unevenly heated, rotating planet. However, the general circulation cannot instantly balance global temperature, especially when the uneven heating is continuous. Therefore, a meridional temperature gradient always remains. In an attempt to balance out Earth's incoming and outgoing energy, warm air is transported toward the poles, while cool air flows back toward the equator. This seems simple enough. However, this seemingly simple flow is complicated by many factors, including Earth's rotation, the position of continents, interactions with the oceans and many others.

Single-Cell Model

The first model we'll examine is the single-cell model. With this model, we make the following assumptions.

1. The earth is entirely covered with water. This is to remove any land-sea interactions.

2. There are no seasons and the sun is always shining directly over the equator. This removes seasonal wind shifts.
3. There is no Coriolis force. While the Earth rotates to spread heat along latitudinal lines, this allows us to only be concerned with the pressure gradient force.

With these assumptions in place, Earth's global circulation would like the figure below (Figure 3), with one giant vertically overturning cell in each hemisphere. The excess heating at the equator is transported poleward by rising warm air, which is replaced by cold sinking polar air moving equatorward. This circulation is known as the **Hadley cell**. The Hadley cell is known as a *thermally direct* circulation because in it, warm air is rising and cold air is sinking.

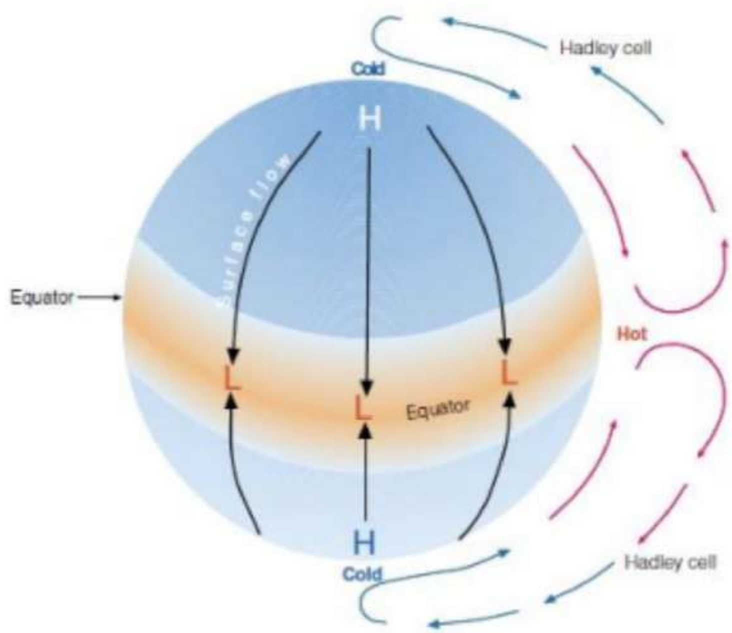


Figure 3: The Single-Cell model of Hadley cells on a planet

The circulation can be thought of in two ways. In the first, hot air at the equator rises because it is warm and buoyant. It reaches the tropopause, spreading laterally north and south at high elevations. To compensate for the rising air, surface air flows toward the equator, resulting in convergence and further uplift. Continuity of this circulation results in a global circulation with rising air at the equator and sinking air at the poles.

A second way to view global circulation is that the excess heating of air at the equator creates a large area of low pressure at the surface of the planet, while excess cooling at the poles creates high pressure at the surface. This global horizontal pressure gradient causes air to flow from high to low at the surface (pole to equator), where the air subsequently rises at the equator and flows back to the poles and sinks.

Both reasonings are plausible, its a matter of whether you focus on temperature or pressure. The temperature differences and the resulting pressure differences are intertwined and both important for the general circulation.

While this single-cell model can explain some phenomenon and works in some ways (and on some planetary bodies), it is not the reality on Earth. Earth is a rotating planet, so we need to consider the Coriolis force in addition to the pressure gradient force. In the single-cell model, as upper level air flows from the equator toward the poles, it would be deflected by the Coriolis force. In the northern hemisphere, for example, this deflection would be toward the right resulting in a wind from west to east at upper levels. In this way, the air moving from the equator to the poles would never make it there because of the rotation of Earth. A different model is needed.

Three-Cell Model

If we allow for the effects of a rotating planet, the simple single-cell model above breaks down into multiple cells in each hemisphere as shown in the figure below. It may look more complex and unrelated to the single-cell model, but there are many similarities from above. There is still excess heating in equatorial regions and excess cooling in Polar Regions. Instead of heat being redistributed by one massive Hadley cell from the equator to the poles, there are now three convective cells. The first of these is still the same thermally direct Hadley cell from before, but now it extends only from the equator to about 30° latitude. The poles still have a large high pressure system, while the equator has a large belt of low pressure along it. Let’s take a closer look at what happens to the rising air just above the equator.

At the equator, the air near the surface is warm, winds are light, and the pressure gradient is weak. This region of monotonous weather is known as the **doldrums** (Figure 4). The warm air here rises, condensing into massive cumulonimbus clouds and thunderstorms, which release large amounts of latent heat as they form. The additional heat makes the air even more likely to rise, and provides the energy that drives the rising branch of the Hadley cell. This rising air reaches the stable tropopause, which blocks it from rising further, causing the air to diverge at upper levels and move poleward. Due to the Coriolis force, this upper level poleward flow is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, providing westerlies aloft (near the tropopause) in both hemispheres in the Hadley cell.

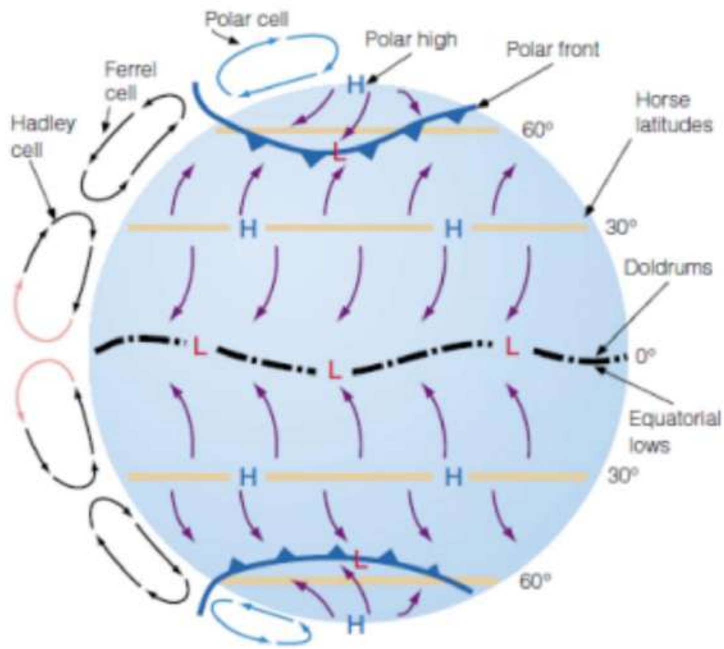


Figure 4: Three-Cell model of the rotating Earth and the resulting wind circulation

As air moves poleward from equatorial regions, it is constantly experiencing radiational cooling as it emits infrared radiation. Simultaneously, this air begins to converge and pile up as it approaches the mid-latitudes (around 30° latitude in both hemispheres). This convergence of air far above the surface increases the mass of air aloft, increasing the pressure at the surface. This increase in surface pressure results in a belt of high pressure centers called **subtropical highs** around 30°N and 30°S. These latitudes are commonly known as the **horse latitudes**.

As this converging air above the subtropical highs slowly descends, it warms adiabatically by compression. This sinking air, dries the atmosphere creating generally clear skies and little rain. Over the oceans, weak pressure gradients in the high centers produce weak winds. Some of these lighter surface winds begin to move back toward the equator, and are deflected by the Coriolis force. This causes northeasterly winds in the Northern Hemisphere and southeasterly winds in the Southern Hemisphere in tropical regions. These winds are known as the **trade winds**, and they have a strong influence over the daily wind patterns in Hawai'i. Near the equator, the northeasterly and southeasterly trade winds converge at the surface at what is known as the **intertropical convergence zone (ITCZ)**. Here, convergence further reinforces the rising branch of the Hadley cell.

Back at 30° latitude, while some of the air sinking along the subtropical highs goes equatorward to complete the Hadley cell, some sinking air also moves poleward. This poleward moving surface air travels from from 30° to 60° and is again deflected by the Coriolis force. This results in the prevailing surface **westerlies** that impact the mid-latitudes in both hemispheres. It is for this reason that weather moves west to east across the continental US. Often, this westerly flow is interrupted by high and low pressure systems that move with the mean surface flow. As the surface air travels poleward from 30° to 60°, it collides with cold polar air moving equatorward. These air masses do not mix easily, and are separated by a boundary known as the **polar front**. At the polar front, surface air converges and rises at the **subpolar low**, and storms and convection develop here. Some of this rising air goes all the way up to the tropopause where it moves back to 30° latitude and sinks at the subtropical high along with the descending branch of the Hadley cell. This circulation cell from 30° to 60° is known as the **Ferrel cell**, which is a *thermally indirect* circulation in which cool air rises and warm air sinks.

Behind the polar front in the Northern hemisphere, cold surface polar air moves from the poles toward 60°. As the air moves equatorward, it is again deflected by the Coriolis force. In the Arctic regions, air typically flows from the northeast while in the Antarctic, air flows from the southeast. These are known as the **polar easterlies**. Along the polar front where cold polar air collides with warm air from the Ferrel cell, some of the rising air moves back toward the poles, which gets deflected as a westerly wind aloft. Eventually this air reaches the poles, sinks back to the surface, and flows back toward the polar front, which gives us the **Polar cell**.

To summarize, looking back at the three-cell model picture: there are two major belts of high pressure and two major belts of low pressure in each hemisphere (if you include the equator in both). Areas of high pressure and sinking air exist near 30° latitude and at the poles. Regions of low pressure and rising air exist over the equator and near 60° latitude by the polar front. By knowing that winds travel counterclockwise (clockwise) around low pressure systems in the Northern Hemisphere (Southern Hemisphere), and clockwise (counterclockwise) around high pressure systems in the Northern Hemisphere (Southern Hemisphere), you can get a pretty general idea of how surface winds blow around the world on average. Trade winds blow from the subtropical highs at 30° to the equator, the westerlies blow from the subtropical highs to the polar front, and the polar easterlies blow from the poles to the polar front at the surface. Areas where these winds converge will have rising motion and low pressure at the surface, and regions where these winds diverge will have sinking motion and high pressure at the surface.

Mechanism of Formation of Indian Monsoon

The climate of India is 'tropical monsoon' type. The term 'monsoon' has been derived from the Arabic word 'mousim' which is characterized by a seasonal reversal in the direction of wind. They flow from sea to land during the summer and from land to sea during the winter due to difference in temperature and pressure system. Monsoons are especially prominent within the tropics on the eastern sides of the great landmass, but in Asia, it occurs also outside the tropics in China, Korea and Japan.

Shifting of ITCZ

This concept was propounded by H. Flohn of German Weather Bureau in 1951. As per him, monsoon system of tropical Asia is a consequence of the seasonal changes in the planetary wind system. These seasonal changes are the result of the seasonal swing of temperature and pressure belts in this region due to changes in overhead position of sun. These planetary winds of tropics are known as trade winds. During the month of March and September, sun is overhead the equatorial area in tropics. This leads to intense heating which creates a belt of low pressure region. This low pressure belt attracts the north-east trade winds from northern hemisphere and south-east trade winds form southern hemisphere. Convergence of these two trade winds in this belt leads to ascending to air which creates a low pressure situation. This low pressure belt this is known as Inter-tropical Convergence Zone (ITCZ; Refer to the lecture material: A Brief Survey of the Atmosphere part2).

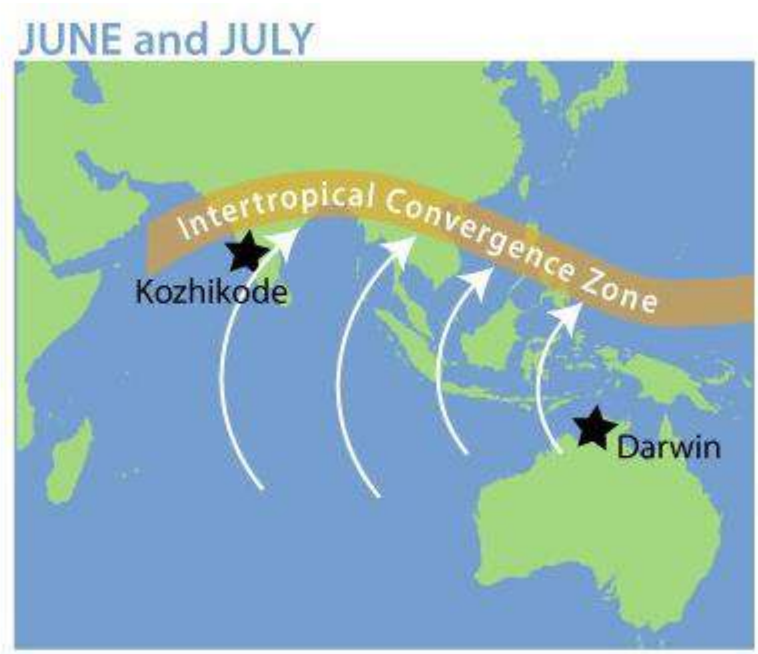


Figure 1: Movement of ITCZ and monsoon over India

With the change in the apparent position of sun towards tropic of cancer, ITCZ changes its position. In July, the ITCZ is located around 20°N-25°N latitudes (over the Gangetic plain), sometimes called the monsoon trough. This monsoon trough creates low pressure area over north and northwest India. Due to this shift of ITCZ, the south-east trade winds of the southern hemisphere cross the equator between 40° and 60°E longitudes. These trade winds change their direction due to the Coriolis force and start blowing from southwest to northeast. Therefore, it is known as ‘southwest monsoon’ (Figure 1). In winter, due to apparent movement of sun toward tropic of Capricorn, the ITCZ moves southward, and so the reversal of wind direction takes place in Indian sun-continent. Now, the wind blows from northeast to southwest. Therefore, winter monsoon is known ‘northeast monsoon’.

Carbon Cycle :- Part - 2

* The Carbon cycle involves chemical transformation.
* It is an inherent from the point of view of climate because it regulates the concentration of two of the atmospheric most important greenhouse gases.
  i.e. CO_2 & CH_4

The table below shows the important carbon reservoir in Earth system & their present capacities [in units of kg/m² average over the Earth's surface & their residence times.

Table # 2

Reservoir	Capacity (kg/m²)	Residence Time
Atm CO_2	1.6	10 years
Atm CH_4	0.01	9 years
Soil & sediments	3	Decades to Millenia
Fossil fuels	10	—
Organic "C" in Sedimentary Rocks	20,000	2×10^8 years
Inorganic "C" in Sedimentary Rocks	80,000	10^8 years

Carbon in atmosphere :-

→ Most of the "C" in the atmosphere is in the form of CO_2.

→ CO_2 is chemically inert → it is relatively well mixed within the atmosphere. Therefore, CO_2 concentration is same even it is released in USA, China, Europe or any parts of the world.

→ CH_4 on the other hand only present in trace concentra but its contribution to the global warming is substantial & CH_4 is chemically active unlike CO_2.

→ CH_4 enters the atmosphere through mining operation & through anaerobic breakdown.

→ CH_4 is removed by the oxidation reaction

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

"As mentioned, it is chemically active & it reacts with "O_2" in the atmosphere -- through the oxidation reaction -- & forms CO_2".

Problem No 2:-

Reconcile the present atmosphere CO_2 concentration of 380 ppm with the mass concentration of elemental carbon in CO_2 given in the table # 2.

Sol:- Vol conc. of CO_2 $\longrightarrow$ 380 ppm (Table from the chemical composition i.e. Table #1)

W.K.T $\quad 1$ ppm $= 0.0001\%$.

From Gravimetric Analysis

$$= (380 \times 0.0001)\% \times \frac{\text{Molecular weight of Carbon}}{\text{Molecular weight of atm. air}}$$

$$\%\text{ in mass} = (380 \times 0.0001)\% \times \frac{12}{28.91}$$

$$= 0.01577\%$$

Before reconciling, we need to estimate the mass of the atmospheric air, we do that by the following method. [by considering the atmospheric pressure].

$\therefore$ Atmospheric Pressure = Force / Unit area

But, Force $F = \rho g \Rightarrow$

$F = m \times v \times g$

per unit volume

$F = \left(\frac{m}{v}\right) \times g$

$= \rho g$

We get the pressure at the surface

$$(P_s) = \int_0^\infty \rho g \, dz$$

$$P_s = M g_0 \quad \ldots\ (1) \quad \text{where, } m = \int_0^\infty \rho \, dz$$

By using (1), we estimate the mass of the atmospheric air in kg/m².

W.K.T $\quad P_s = 9.85 \times 10^4$ Pa or kg/m·s²

$$P_s = M g_0$$

$$9.85 \times 10^4 = M \times 9.81 \ (m/s^2)$$

$M = 1.004 \times 10^4 \; kg/m^2$

But we also know the radius of the earth i.e.

$6.37 \times 10^6 \; m$

$\therefore$ Mass of the atmosphere in terms of kg

$= 1.004 \times 10^4 \; (kg/m^2) \times 4 \times \pi \times (R)^2$

↳ Radius of the Earth

$= 1.004 \times 104 \; (kg/m^2) \times 4 \times \pi \times (6.37 \times 106)^2$

$= 5.1 \times 10^{18} \; kg$ → Atmospheric air above us

Now, we have to reconcile the Atmospheric CO_2 based on the mass of the air we just computed.

Percent CO_2 concentration $= (0.01577\,\%) \times$ Mass of the air

↑ From gravimetric analysis

$= (0.01577\,\%) \times 1.004 \times 104 \left(\frac{kg}{m^2}\right)$

$= 0.01577 \times 1.004 \times 104$

$= 1.59 \; kg/m^2$

We have now reconciled as the value we got is similar to the value which is given in Table # 2

Problem 3

The present rate of consumption of fossil fuel is 7 GtC/year. Based on the data given in the table # 2, how long would it take to deplete the entire fossil fuel reservoir of the fossil fuel if consumption continues at the present rate.

Soln:- Fixed consumption rate of 7 GtC/year

$= 7 \times 10^9 \times 10^3$ kg/year

$= 7 \times 10^{12}$ kg/year

Total fossil fuel reserve = (given in the table # 2)
10 kg/m^2

Please remember, the value "10 kg/m^2" is average over the surface of the earth ∴ to get this kg/m^2 to kg, we have to multiply $4\pi R^2$ to the 10 kg/m^2 where 'R' is the radius of the earth.

∴ Total fossil fuel $= 10\ (\text{kg/m}^2) \times 4\pi R^2$

$= 10\ (\text{kg/m}^2) \times 4\pi \times (6.37 \times 10^6)^2$

$= 5.09 \times 10^{15}$ kg $\simeq 5100$ Gt

Time to deplete fossil fuel Reserve

$$= \frac{5100 \text{ Gt}}{7 \text{ Gt (Fixed rate of consumption)}} = 728.5 \text{ years}$$

CARBON IN THE BIOSPHERE:

On shorter time scale, large quantities of carbon pass back & forth b/w the atmosphere & biosphere.

⇓

by photosynthesis reaction

$$CO_2 + H_2O \longrightarrow \underbrace{H_2CO}_{\text{Carbohydrate}} + O_2 \longrightarrow \text{helps in sustenance of life}$$

Removes "C" from the atmosphere & stores in organic molecules (carbohydrate) in phytoplankton & leafy plants.

How CO_2 will again enter the atmosphere?

Respiration & Decay Reaction $\quad H_2CO + O_2 \longrightarrow CO_2 + H_2O$

↓

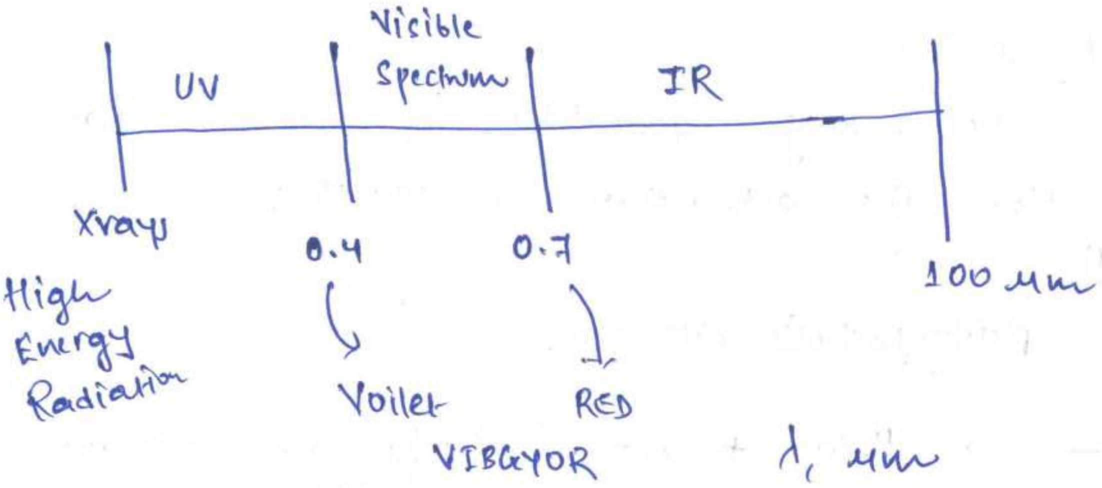
Organic matter is oxidized & CO_2 is returned to the atmosphere

⇒ During photosynthesis, phytoplankton & plants absorbs energy in the form of visible light at λ near 0.43 μm (blue) & 0.66 μm (orange)

⇓

Electromagnetic Spectrum ⟶ More detailed in atm radiation

Some amount will be released back during respiration & decay in the form of heat.



$E = h\nu$
(Energy of a photon)

$E = \frac{hc}{\lambda}$ → Speed of light in Vaccum

$\lambda \uparrow \; E \downarrow$

When λ is small, you have high energy

h = Planc's constant
$= 6.6 \times 10^{-34}$ J.s

How do we measure the amount of Photosynthesis?
⇒ It can be measured through the remote sensing by comparing the intensity of reflected radiation at various wavelengths in the visible part of the spectrum. It is possible to estimate the photosynthesis, we get a estimate of NET PRIMARY PRODUCTIVITY

NPP → It is not a measurement but it is a satellite derived estimate.

- NPP
  - Ocean → Phytoplankton
  - Land → Leafy Plants

- PROBLEM:

Reconcile the retention time of the atmospheric CO_2 given the rate of exchange of 'c' b/w the atmosphere & biosphere is $\approx$ 0.1 to 0.2 kg c/m² year.

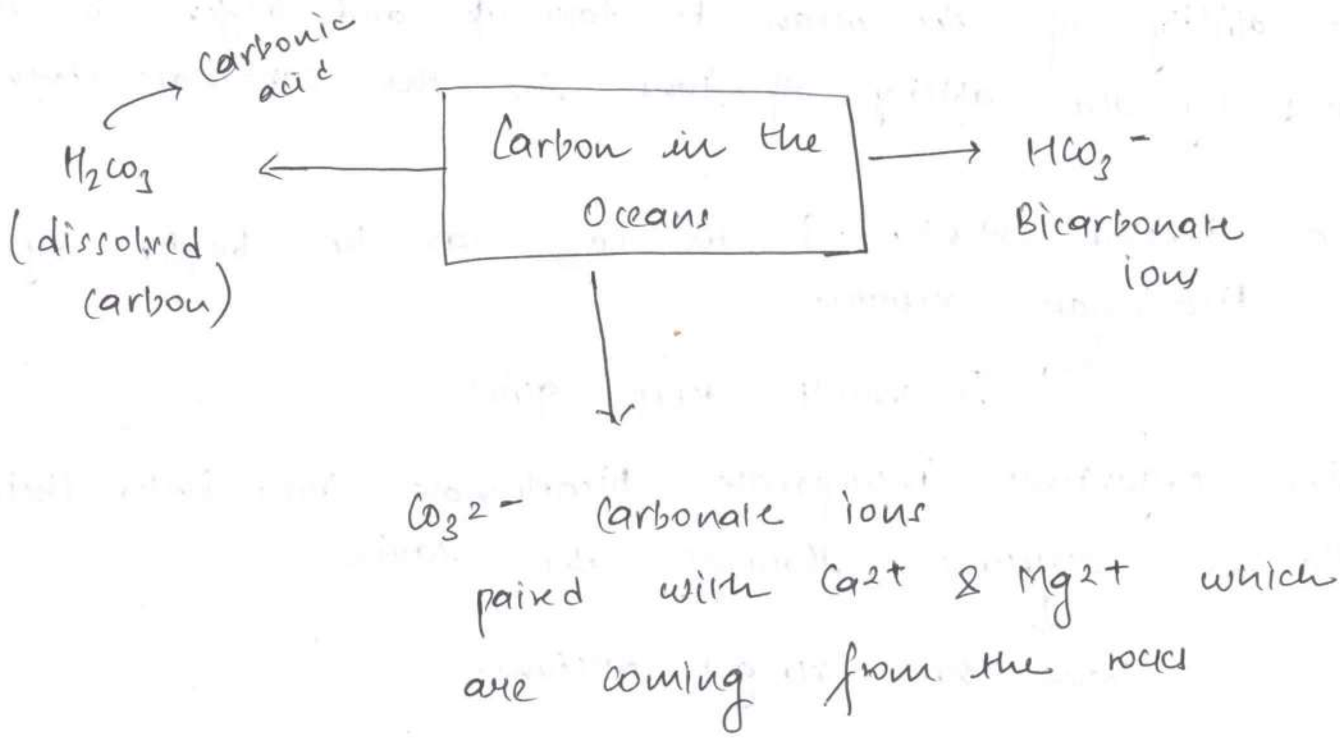
Sol: From the table,

CO_2 in atm = 1.6 kg/m²

$$\therefore \frac{1.6 \text{ kg c/m}^2}{0.15 \text{ kg c/m}^2\text{-year}}$$

= 10.6 years

CARBON IN THE OCEANS :-



Some Reactions :-

$$CO_2 + H_2O \rightleftharpoons \underbrace{H_2CO_2}_{\text{Carbonic acid}} \quad \cdots (1)$$

$$H_2CO_3 \rightleftharpoons H^+ + \underbrace{HCO_3^-}_{\text{Bicarbonate}} \quad \cdots (2)$$

$$HCO_3^- \rightleftharpoons H^+ + \underbrace{CO_3^{2-}}_{\text{carbonate}} \quad \cdots (3)$$

The net effect is obtaining by adding 1 & 2, & the reverse of 3

Adding (1) & (2)

$$CO_2 + H_2O \rightleftharpoons \cancel{H_2CO_3}$$

$$\cancel{H_2CO_3} \rightleftharpoons H^+ + HCO_3^-$$

$$CO_2 + H_2O \rightleftharpoons \cancel{H^+} + HCO_3^-$$

$$\cancel{H^+} + CO_2^{2-} \rightleftharpoons HCO_3^-$$

$$CO_2 + CO_3^{2-} + H_2O \rightleftharpoons 2HCO_3^- \quad \ldots\ldots (4)$$

↓

added CO_2 into the bicarbonate reservoir without any net increase in the acidity of the ocean.

This ability of the ocean to take up and buffer CO_2 is limited by the ability of ions in the carbonate reservoir.

To a limited extent, ↑ in CO_2 can be buffer by the bicarbonate reservoir

↳ It won't keep quiet

Marine organisms incorporate bicarbonate ions into their shells & skeletons through the reaction.

↓

From here we get calcium

$$Ca^{2+} + 2HCO_3^- \longrightarrow CaCO_3 + H_2CO_3 \quad \ldots\ldots (5)$$

Organic form

$CaCO_3$ ↓ Limestone

H_2CO_3 ↓ Carbonic Acid

↓

will continue with the process

CO_2 is very nicely getting settled down as limestone. If you have the technology to do so, then you can burn as much as CO_2, but we don't have that. Only limited CO_2 is getting dissolved as limestone.

Fraction $CaCO_3$ → settle down the sea floor & forms the limestone. While the remainder

$$CaCO_3 + H_2CO_3 \longrightarrow Ca^{2+} + 2HCO_3^- \quad \ldots\ (6)$$

Inorganic source of Ca^{2+} → are also derived from weathering of calcium silicate rocks.

$$CaSiO_3 + 2H_2CO_3 \longrightarrow Ca^{2} + 2HCO_3^- + SiO_2 + H_2O \quad \ldots\ (7)$$

↓ Important for the capture of CO_2

Combining 6 & 7,

$$CaSiO_3 + 2\cancel{H_2}CO_3 \longrightarrow \cancel{Ca^{2+}} + \cancel{2HCO_3^-} + SiO_2 + H_2O$$

$$\cancel{CO_2 + 2HCO_3^- \longrightarrow H_2CO_3^-}$$

$$\cancel{Ca^{2+}} + \cancel{2HCO_3^-} \longrightarrow CaCO_3 + \cancel{H_2CO_3}$$

$$CaSiO_3 + H_2CO_3 \longrightarrow CaCO_3 + SiO_2 + \cancel{H_2O}$$

$$CO_2 + \cancel{H_2O} \longrightarrow H_2CO_3$$

$$\underbrace{CaSiO_3 + CO_2 \longrightarrow CaCO_3 + SiO_2}$$

⇓

Inorganic carbon sedimentary rocks in the Earth Crust

↳ carbon sequestration