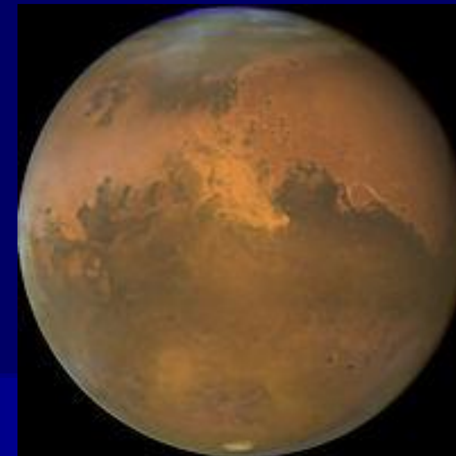
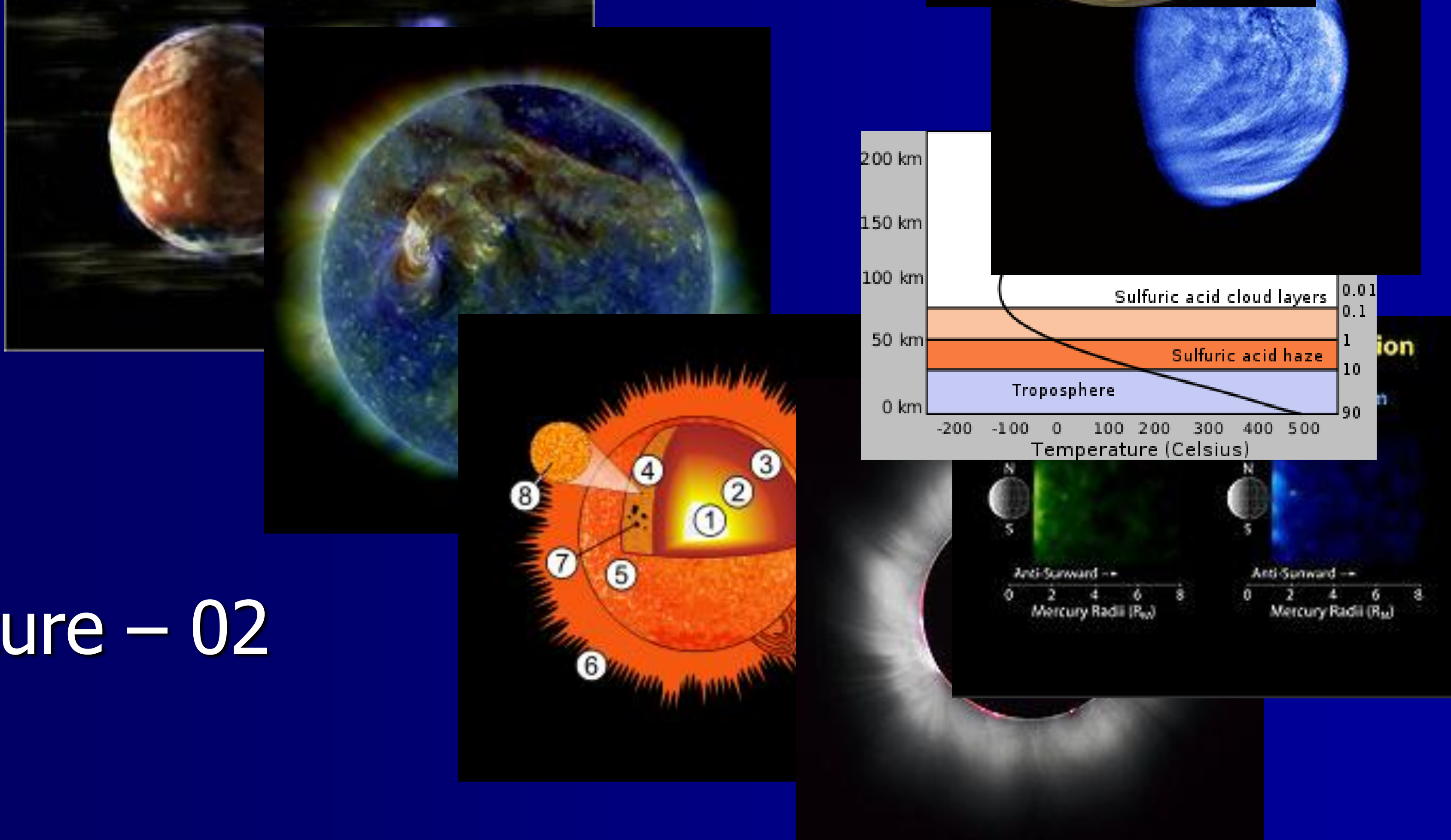
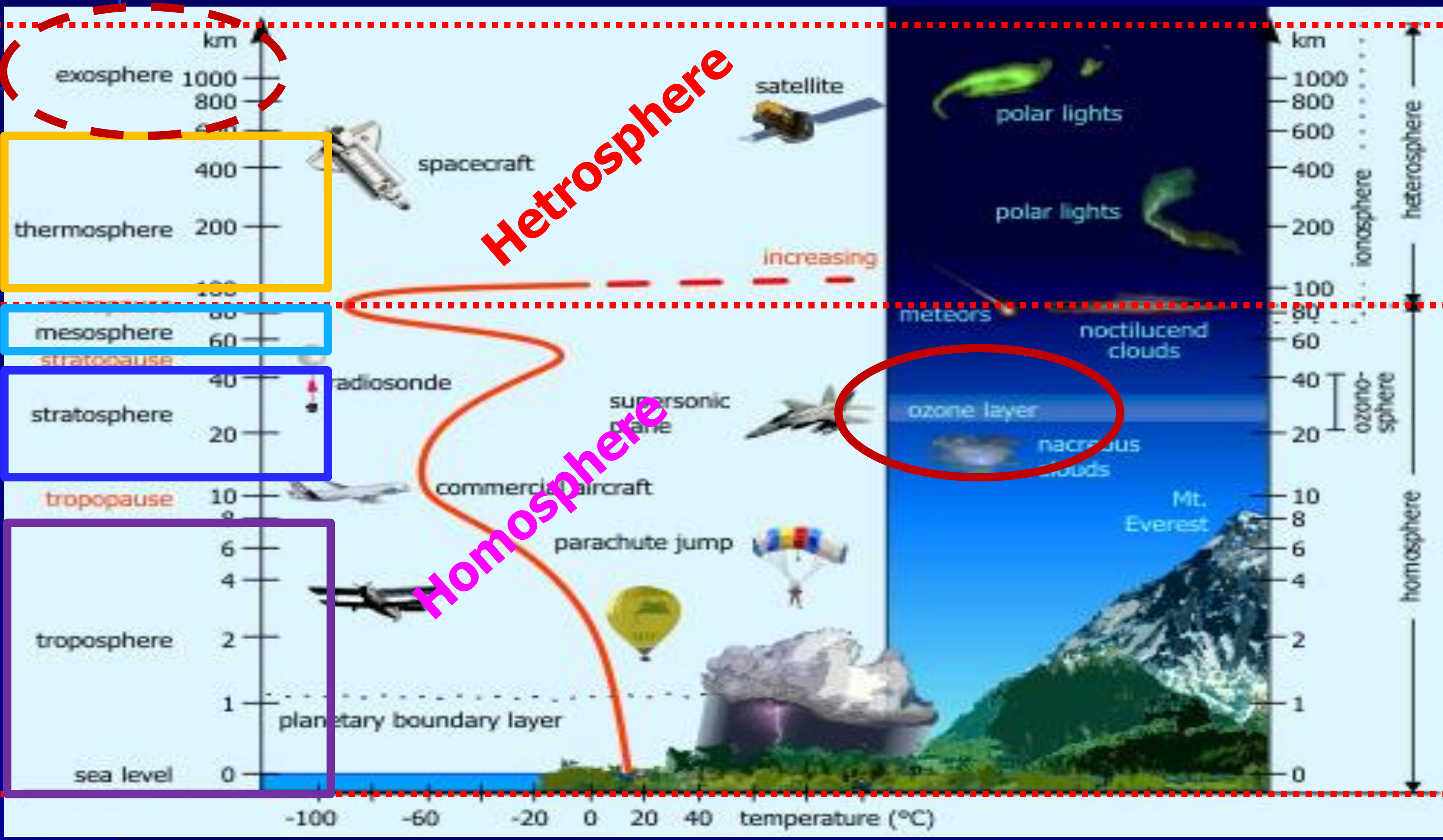
Space Physics





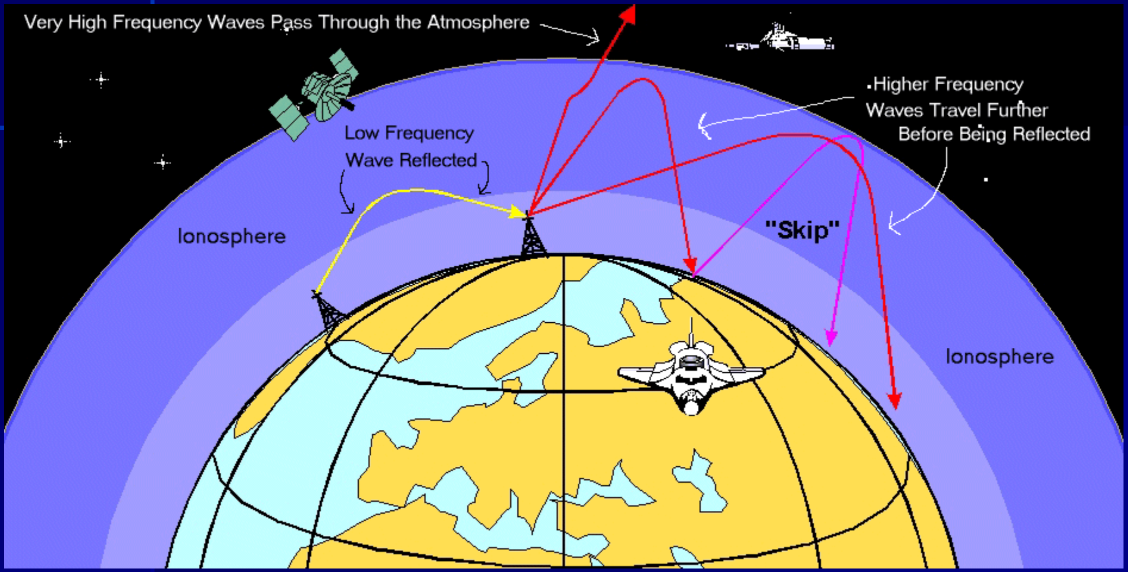
Lecture – 02

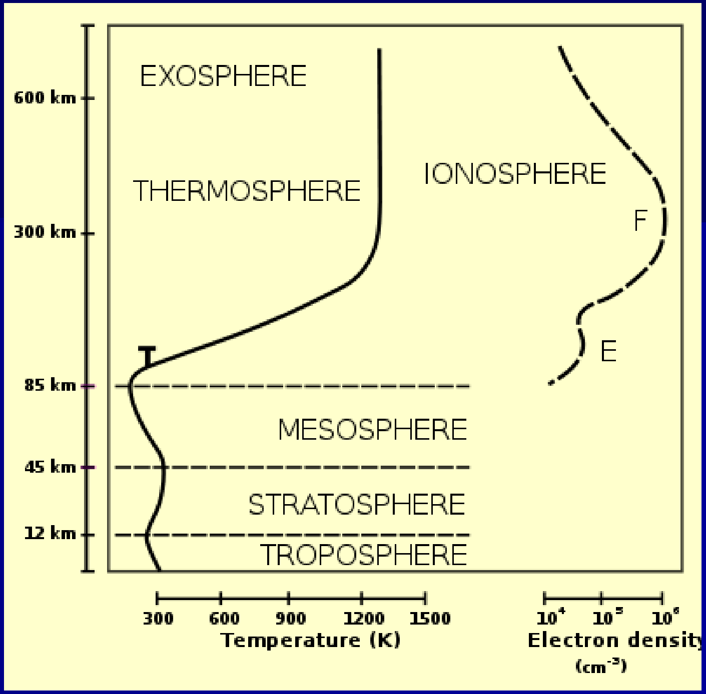
The Structure of the Terrestrial Atmosphere

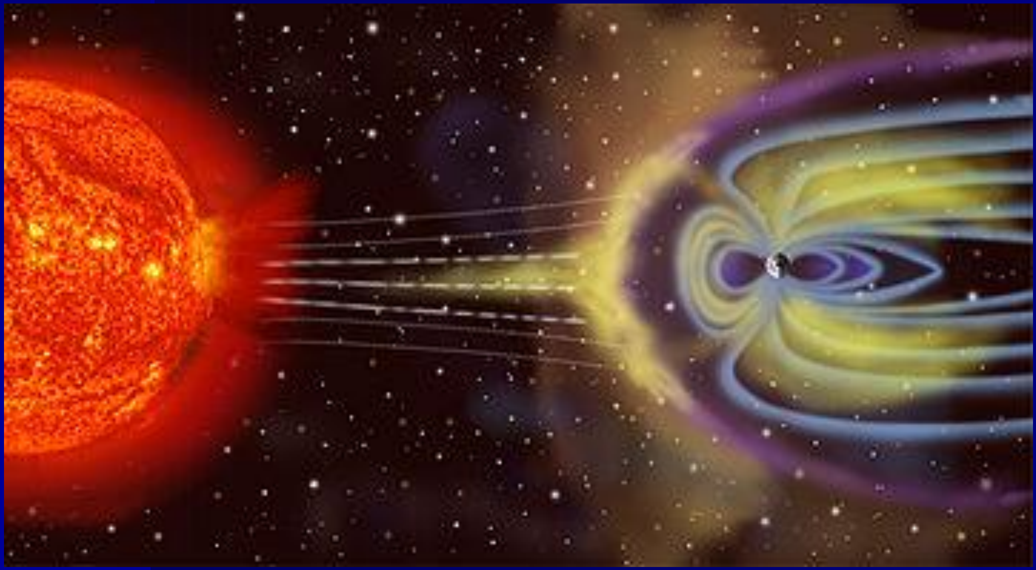


The Structure of the Terrestrial Atmosphere

Ionosphere:







Magnetosphere:

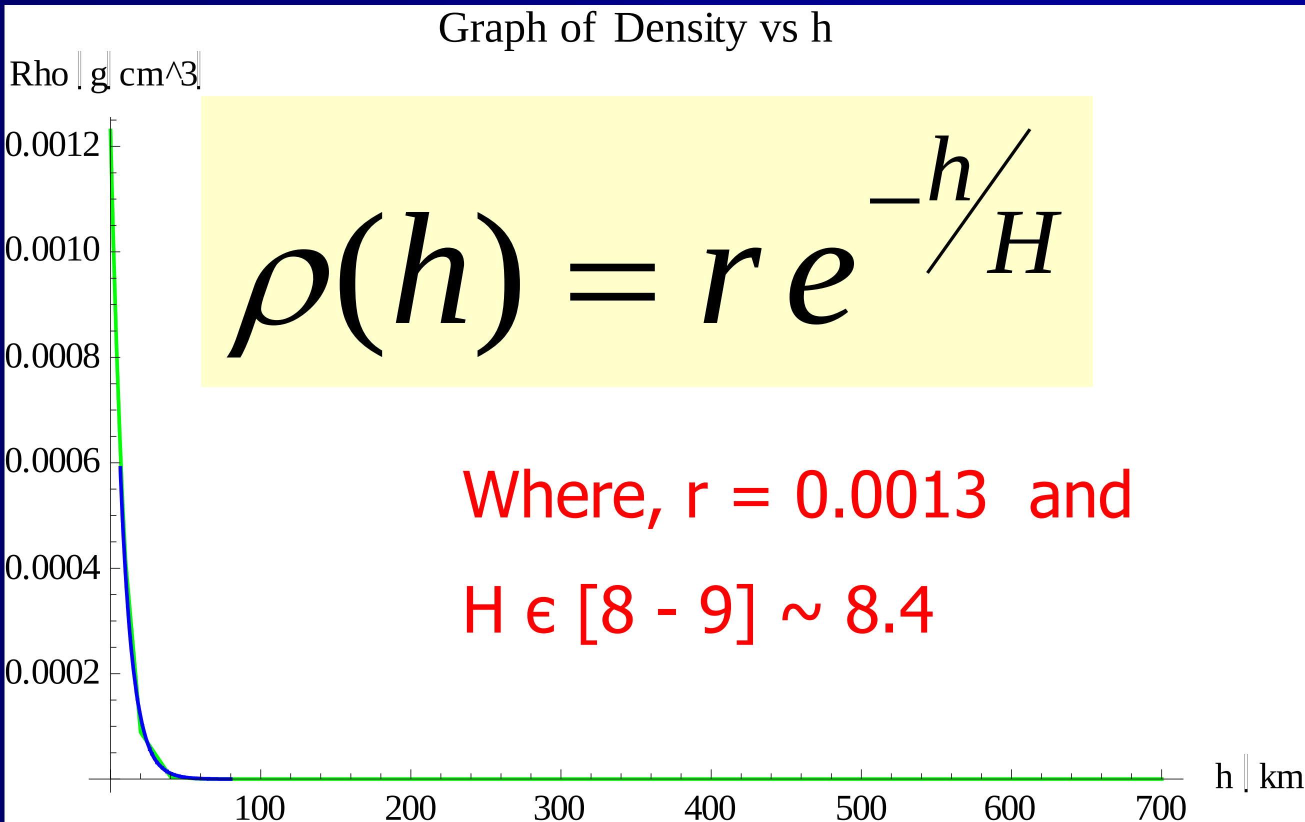
The physical parameters of an average atmosphere.

TABLE 1.2-I

Altitude in km	Temperature in °K	Density in gr/cm^{-3}	Mean Mol. Weight	Pressure in dyn/cm^2	Mean Free Path in m	Accel. Grav. in cm/s^2
0	288	1.23×10^{-3}	28.96	1.01×10^{6}	6.63×10^{-8}	981
2	275	1.01×10^{-3}	28.96	7.95×10^{5}	8.07×10^{-8}	980
4	262	8.19×10^{-4}	28.96	6.17×10^{5}	9.92×10^{-8}	979
6	249	6.60×10^{-4}	28.96	4.72×10^{5}	1.23×10^{-7}	979
8	236	5.26×10^{-4}	28.96	3.57×10^{5}	1.55×10^{-7}	978
10	223	4.14×10^{-4}	28.96	2.65×10^{5}	1.96×10^{-7}	978
20	217	8.89×10^{-5}	28.96	5.53×10^{4}	9.14×10^{-7}	975
40	250	4.00×10^{-6}	28.96	2.87×10^{3}	2.03×10^{-5}	968
60	256	3.06×10^{-7}	28.96	2.25×10^{2}	2.66×10^{-4}	962
80	181	2.00×10^{-8}	28.96	1.04×10	4.07×10^{-3}	956
100	210	4.97×10^{-10}	28.88	3.01×10^{-1}	1.63×10^{-1}	951
140	714	3.39×10^{-12}	27.20	7.41×10^{-3}	2.25×10	939
180	1156	5.86×10^{-13}	26.15	2.15×10^{-3}	1.25×10^{2}	927
220	1294	1.99×10^{-13}	24.98	8.58×10^{-4}	3.52×10^{2}	916
260	1374	8.04×10^{-14}	23.82	3.86×10^{-4}	8.31×10^{2}	905
300	1432	3.59×10^{-14}	22.66	1.88×10^{-4}	1.77×10^{3}	894
400	1487	6.50×10^{-15}	19.94	4.03×10^{-5}	8.61×10^{3}	868
500	1499	1.58×10^{-15}	17.94	1.10×10^{-5}	3.19×10^{4}	843
600	1506	4.64×10^{-16}	16.84	3.45×10^{-6}	1.02×10^{5}	819
700	1508	1.54×10^{-16}	16.17	1.19×10^{-6}	2.95×10^{5}	796

The graph of h (in km) vs Density (in gr cm^(-3))

Altitude in km	Density in gr/cm^{-3}
0	1.23×10^{-3}
2	1.01×10^{-3}
4	8.19×10^{-4}
6	6.60×10^{-4}
8	5.26×10^{-4}
10	4.14×10^{-4}
20	8.89×10^{-5}
40	4.00×10^{-6}
60	3.06×10^{-7}
80	2.00×10^{-8}
100	4.97×10^{-10}
140	3.39×10^{-12}
180	5.86×10^{-13}
220	1.99×10^{-13}
260	8.04×10^{-14}
300	3.59×10^{-14}
400	6.50×10^{-15}
500	1.58×10^{-15}
600	4.64×10^{-16}
700	1.54×10^{-16}



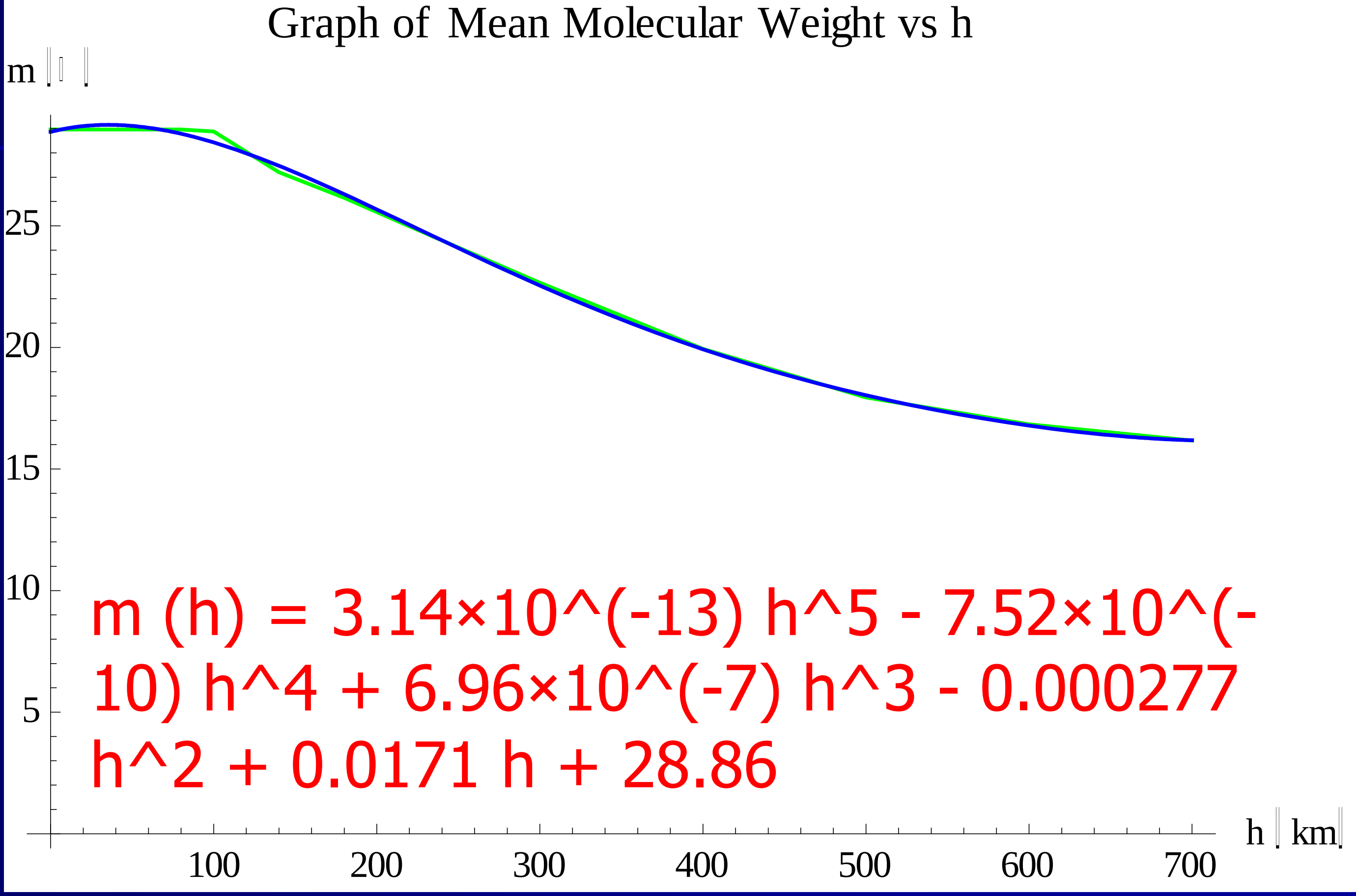
$$\rho(h) = r\, e^{-h/H}$$

Where, r = 0.0013 and

H ϵ [8 - 9] ~ 8.4

The graph of h (in km) vs m

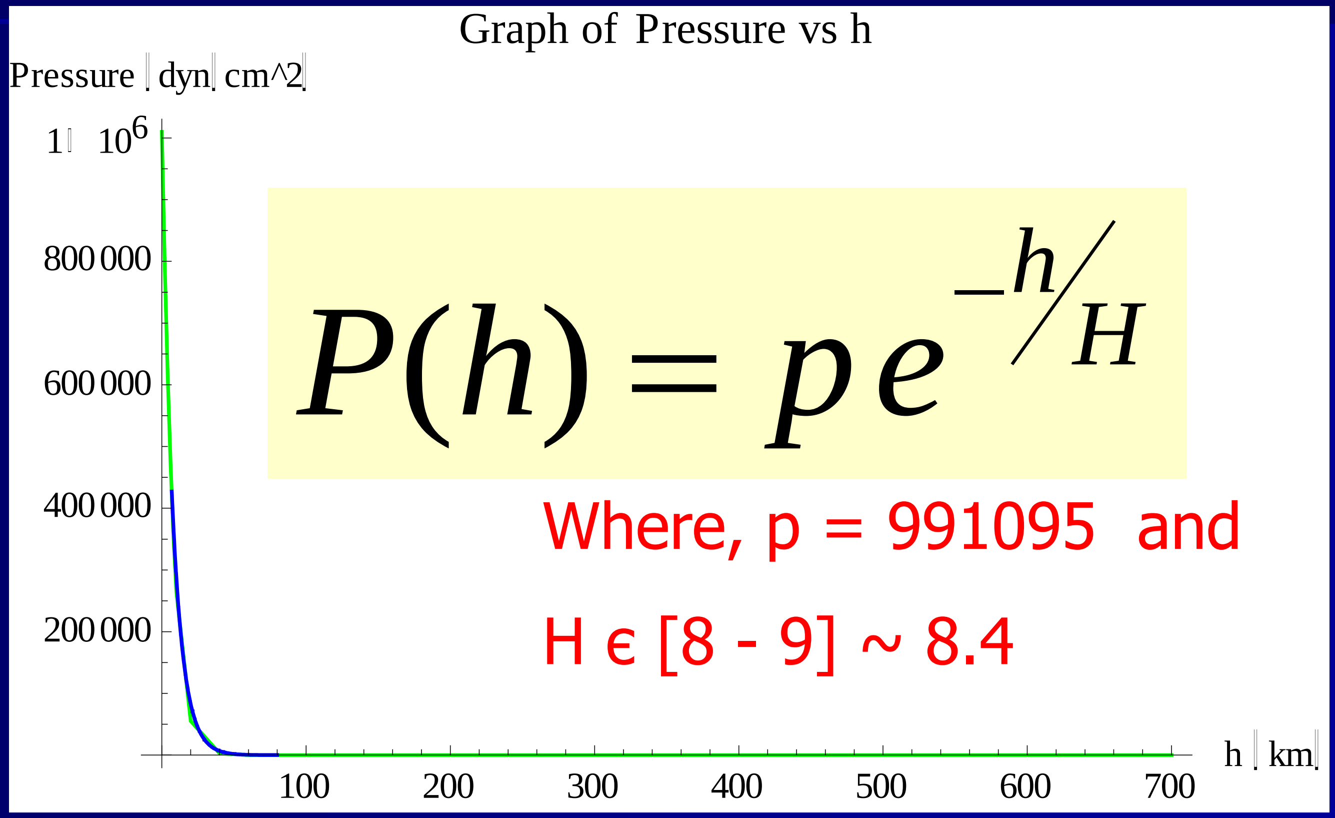
Altitude in km	Mean Mol. Weight
0	28.96
2	28.96
4	28.96
6	28.96
8	28.96
10	28.96
20	28.96
40	28.96
60	28.96
80	28.96
100	28.88
140	27.20
180	26.15
220	24.98
260	23.82
300	22.66
400	19.94
500	17.94
600	16.84
700	16.17



$$m(h) = 3.14\times10^{-13} h^5 - 7.52\times10^{-10} h^4 + 6.96\times10^{-7} h^3 - 0.000277 h^2 + 0.0171 h + 28.86$$

The graph of h (in km) vs Pressure (in dyn/cm^2)

Altitude in km	Pressure in dyn/cm²
0	1.01×10^6
2	7.95×10^5
4	6.17×10^5
6	4.72×10^5
8	3.57×10^5
10	2.65×10^5
20	5.53×10^4
40	2.87×10^3
60	2.25×10^2
80	1.04×10
100	3.01×10^{-1}
140	7.41×10^{-3}
180	2.15×10^{-3}
220	8.58×10^{-4}
260	3.86×10^{-4}
300	1.88×10^{-4}
400	4.03×10^{-5}
500	1.10×10^{-5}
600	3.45×10^{-6}
700	1.19×10^{-6}



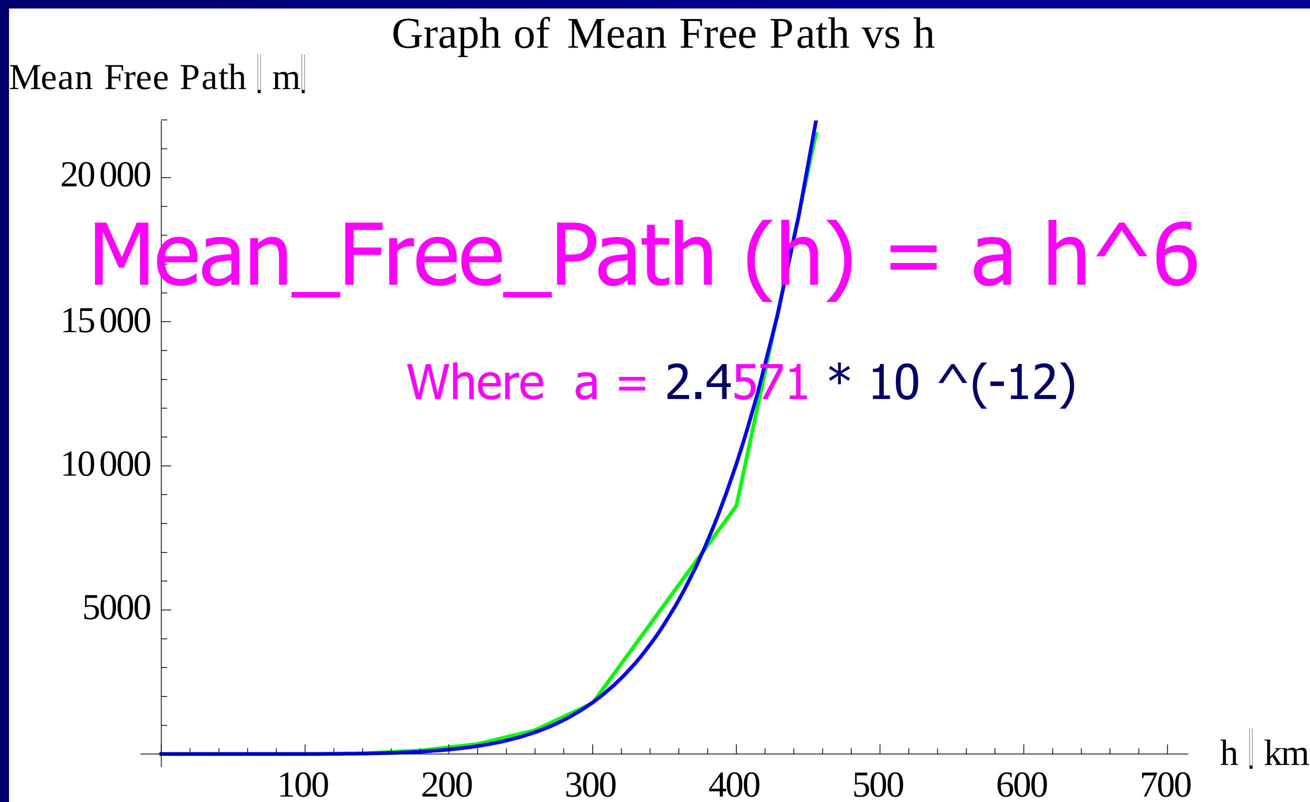
$$P(h) = p\,e^{-h/H}$$

Where, p = 991095 and

H ϵ [8 - 9] ~ 8.4

The graph of h (in km) vs Mean Free Path (in m)

Altitude in km	Mean Free Path in m
0	6.63×10^{-8}
2	8.07×10^{-8}
4	9.92×10^{-8}
6	1.23×10^{-7}
8	1.55×10^{-7}
10	1.96×10^{-7}
20	9.14×10^{-7}
40	2.03×10^{-5}
60	2.66×10^{-4}
80	4.07×10^{-3}
100	1.63×10^{-1}
140	2.25×10
180	1.25×10^{2}
220	3.52×10^{2}
260	8.31×10^{2}
300	1.77×10^{3}
400	8.61×10^{3}
500	3.19×10^{4}
600	1.02×10^{5}
700	2.95×10^{5}

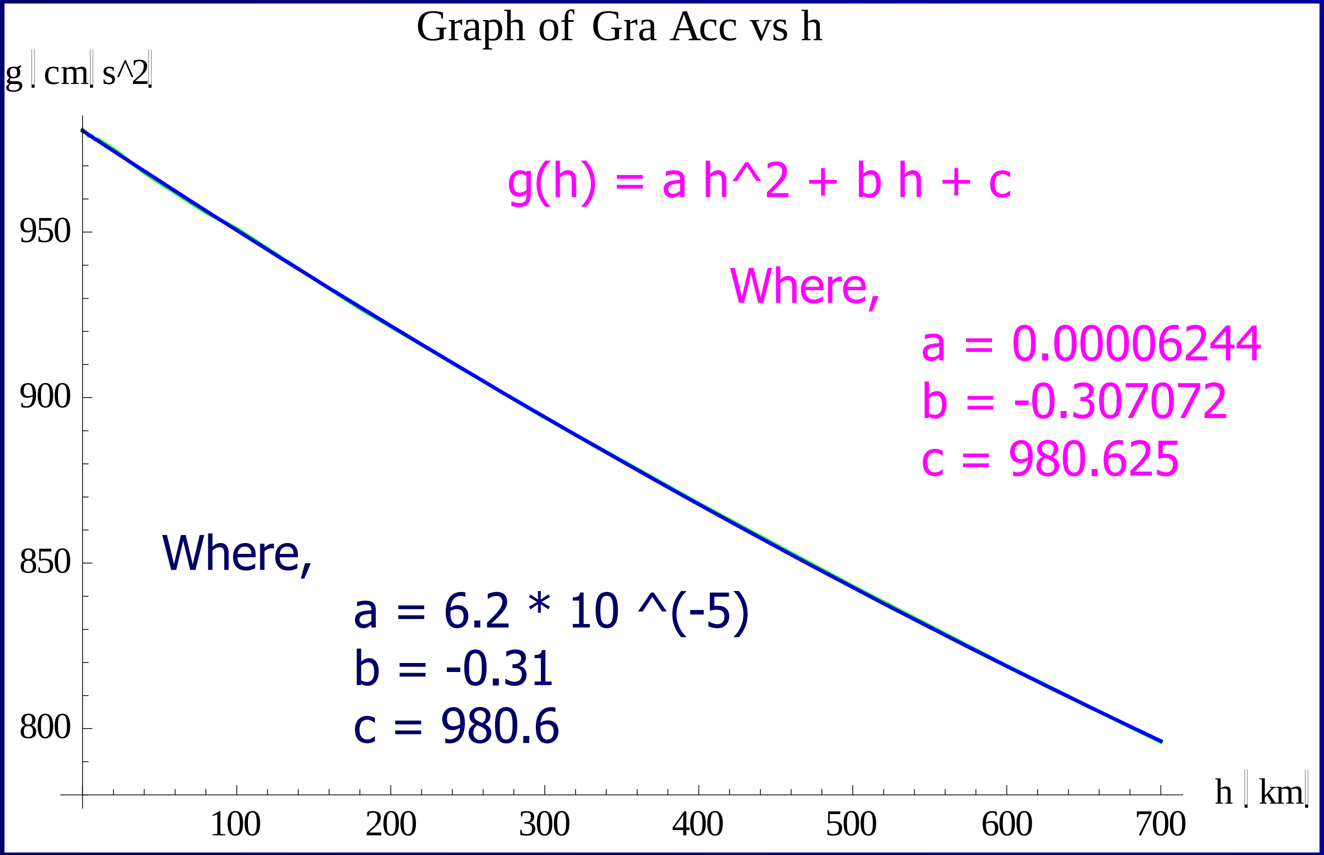


Mean_Free_Path (h) = a h^6

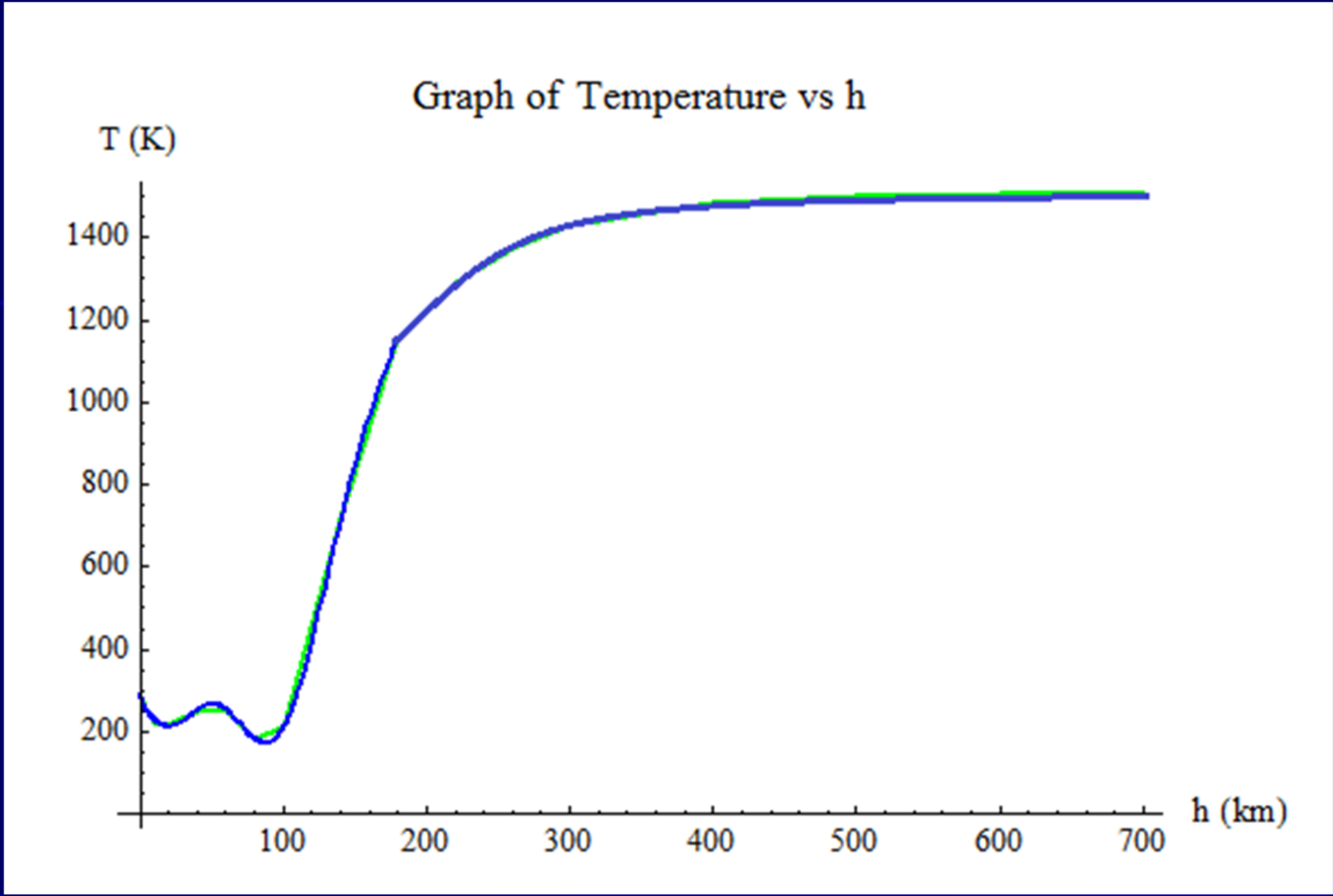
Where a = 2.4571 * 10 ^(-12)

Altitude in km	Accel. Grav. in cm/s²
0	981
2	980
4	979
6	979
8	978
10	978
20	975
40	968
60	962
80	956
100	951
140	939
180	927
220	916
260	905
300	894
400	868
500	843
600	819
700	796

The graph of h (in km) vs Gravitational Acceleration (in cm/s^2)



Altitude in km	Temperature in °K
0	288
2	275
4	262
6	249
8	236
10	223
20	217
40	250
60	256
80	181
100	210
140	714
180	1156
220	1294
260	1374
300	1432
400	1487
500	1499
600	1506
700	1508



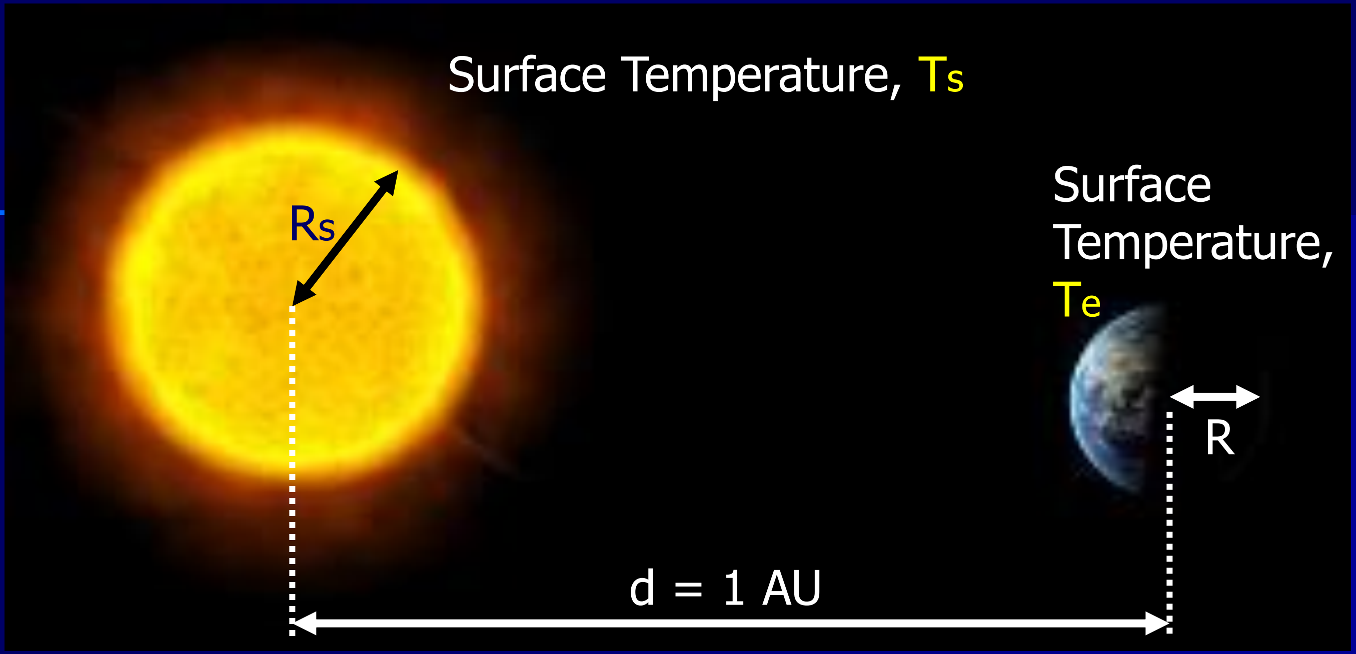
$$T(h) = \begin{cases} 3.4\times10^{-7}h^5 - 4.2\times10^{-5}h^4 - 1.3\times10^{-3}h^3 & 0km \le h \le 100km \\ +2.9\times10^{-1}h^2 - 8.98h + 290.3 & \\ 2.0\times10^{-10}h^5 - 4.8\times10^{-7}h^4 + 4.5\times10^{-4}h^3 & \\ -2.1\times10^{-1}h^2 + 47.7h - 2895.7 & 100km < h \le 700km \end{cases}$$

Planetary Atmospheres

Planetary Atmospheres

The Structure of the Terrestrial Atmosphere
The Temperature of the Neutral Atmosphere
The Escape of the Atmospheric Gases
The Atmospheres of the Earth

The Temperature of the Neutral Atmosphere



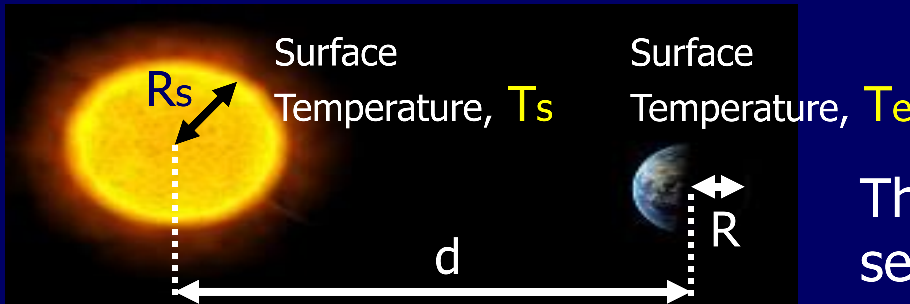
AL Method

$$\sigma = 5.67 \times 10^{-8} \; J s^{-1} m^{-2} K^{-4}$$

$$T_S = 5778\,K \;\; (\sim 6000\,K)$$

$$R_S = 695500 \; km \;\; (\sim 7 \times 10^{5} \; km)$$

$$d = 149\,598\,000 \; km \;\; (1AU)$$



Using Stephan's Law;

The **Energy** emitted per unit area, per second by the Sun = $E = \sigma T_S^{\ 4}$

The **Total Energy** emitted per second by the Sun = $\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}$

The Energy Density per second (Energy per unit area) at our orbit = $\dfrac{\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}}{4\pi d^2}$

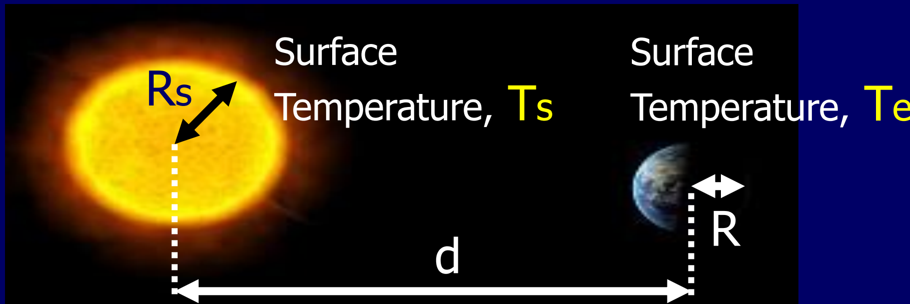
Where this ***d*** is distance from the Sun to the Earth's Orbit (1.0 AU)

The Total Energy to the Earth = $\dfrac{\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}}{4\pi d^2} \times \pi R^2$ $\longrightarrow$ 1

The Energy absorbed by the Earth = $e\sigma T_e^{\ 4} \times 2\pi R^2$ $\longrightarrow$ 2

Using Stephan's Law

Where this ***e*** is emissivity of the Earth (Factor per BB, for BB ; e=1)



Connect equation 1 & 2 ;

$$\frac{\sigma T_S{}^4 \times 4\pi R_S{}^2}{4\pi d^2} \times \pi R^2 = e\,\sigma T_e{}^4 \times 2\pi R^2$$

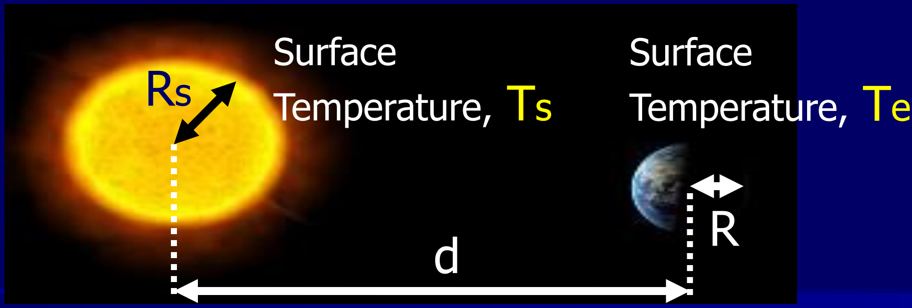
Where *e* should be [0 – 1]

$$T_e{}^4 = \frac{\sigma T_S{}^4 \times 4\pi R_S{}^2 \times \pi R^2}{4\pi d^2 \times e\,\sigma \times 2\pi R^2}$$

$$T_e = \left(\frac{T_S{}^4 \times R_S{}^2}{e\,d^2 \times 2}\right)^{1/4}$$

$$T_e = \{1047.62, 589.123, 393.97, 340.13, 332.121, 331, 288\}\ C$$

???



Space Physics 01.nb * - Wolfram Mathematica 10.0

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```
In[61]:= sig = 5.67 * (10 ^ (-8)); (* in J/s m^2 K^4 *)
ts = 5778; (* in K *)
rs = 695500 * 1000; (* in m *)
re = 6400 * 1000; (* in m *)
d = 149598000 * 1000; (* in m *)
e = {0.01, 0.1, 0.5, 0.9, 0.99, 1.0} ; (* e in between 0 and 1 *)

te = (  ((ts^4) * (rs^2)) / (e * (d^2) * 2)  )^(1/4);
Print["Temperature on the Earth is : ", te - 273, " C"]

Temperature on the Earth is : {774.625, 316.123, 120.97, 67.1301, 59.1214, 58.288} C
```

Solar Flux at 1 AU

$$S_o = \sigma T_S{}^4 \left(\frac{R_S}{d}\right)^2$$

Where,

$$\sigma = 5.67 \times 10^{-8}\ Js^{-1}m^{-2}K^{-4}$$

$$T_S = 5778\,K \ \ (\sim 6000\,K)$$

$$R_S = 695500\ km\ (\sim 7 \times 10^5\ km)$$

$$d = 149\,598\,000\,km\ (1AU)$$

$$S_o = 1365.95\ \ Jm^{-2}s^{-1}$$

in our orbit...

The value of the effective temperature of the Earth,

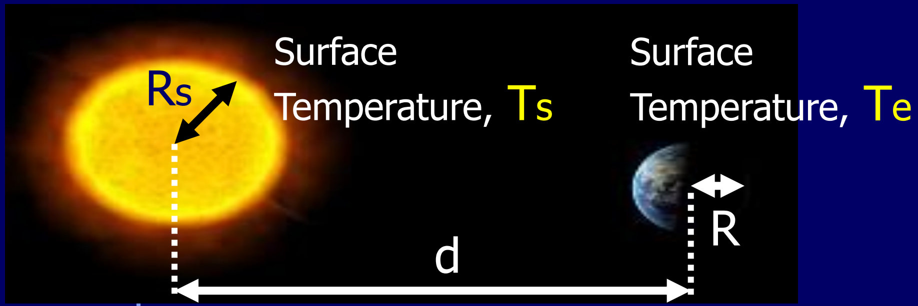
$$T_e = \left(\frac{R_S}{d}\right)^{1/2} \left(\frac{1-A}{4}\right)^{1/4} T_S$$

Where, $A = 0.4$

Albedo of the Earth...

Let the reflectivity of this sphere be such that it reflects a fraction *A* (Albedo) and absorbs the remaining fraction (*1 – A*) of the incoming solar radiation.

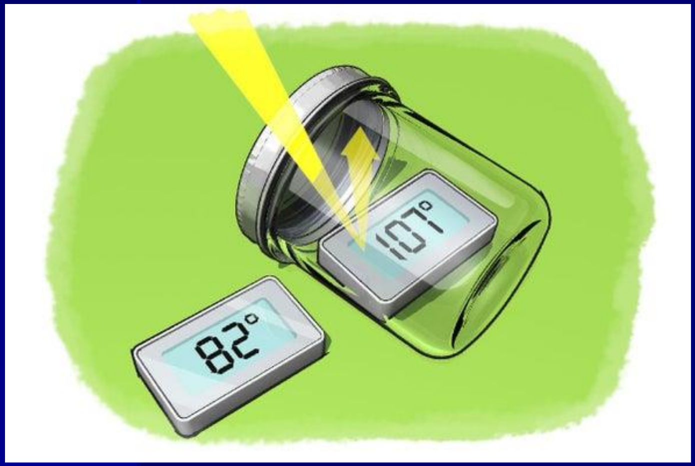
$$T_e = 245.181\,K$$



The value of ground temperature of the Earth,

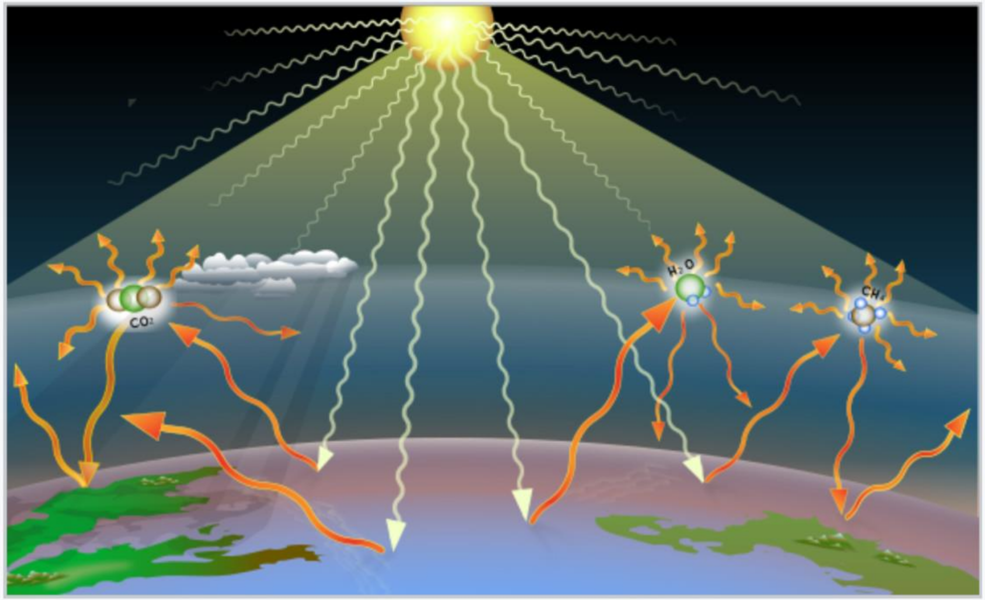
$$\Rightarrow \quad \boxed{T_e = 305K}$$

The temperature obtained in the above is somewhat higher than the average temperature on the surface on the Earth, but still it describes to a good approximation the Green House Effect.



In a greenhouse sunlight—which is made up of different wavelengths, some of which are in the visible and infrared spectrum—shines through the transparent glass or plastic roof and walls. Only the light in the visible spectrum can penetrate into the greenhouse whereas incoming infrared light, which is also known as heat radiation, is blocked by the glass or plastic.

Inside the greenhouse the visible light is absorbed by the plants and soil and is converted into heat, which is then emitted by the plants and soil in form of infrared radiation. Because that heat radiation is blocked by the glass, most of it cannot escape, and the temperatures inside the greenhouse will steadily increase.

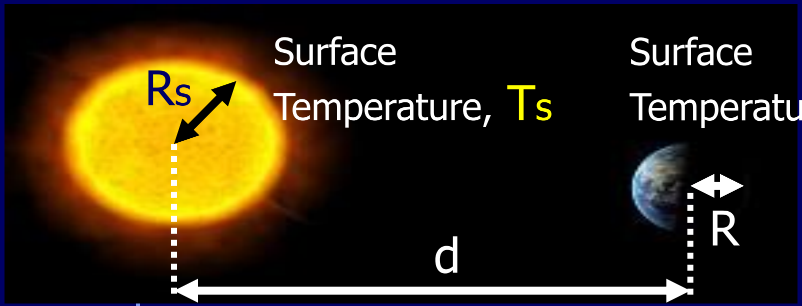


Light energy (white arrows) emitted by the sun warms the earth's surface, which reflects the energy as heat (orange arrows) that warms the atmosphere. Much of the heat is captured by greenhouse gas molecules such as water, carbon dioxide, and methane.

The **greenhouse effect** is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without this atmosphere.

Radiatively active gases in a planet's atmosphere radiate energy in all directions. Part of this radiation is directed towards the surface, warming it. The intensity of the downward radiation that is, the strength of the greenhouse effect will depend on the atmosphere's temperature and on the amount of greenhouse gases that the atmosphere contains.

Earth's natural greenhouse effect is critical to supporting life, and initially was a precursor to life moving out of the ocean onto land. Human activities, however, mainly the burning of fossil fuels and clearcutting of forests, have accelerated the greenhouse effect and caused global warming.



The value of ground temperature of the Earth,

$$\boxed{T_e = 305\,K}$$

The temperature obtained in the above is somewhat higher than the average temperature on the surface on the Earth, but still it describes to a good approximation the Green House Effect.

The small excess we have found in T_g occurs in part because we have neglected the convective transport of heat in the lower atmosphere, which would tend to cool down the surface of the Earth.

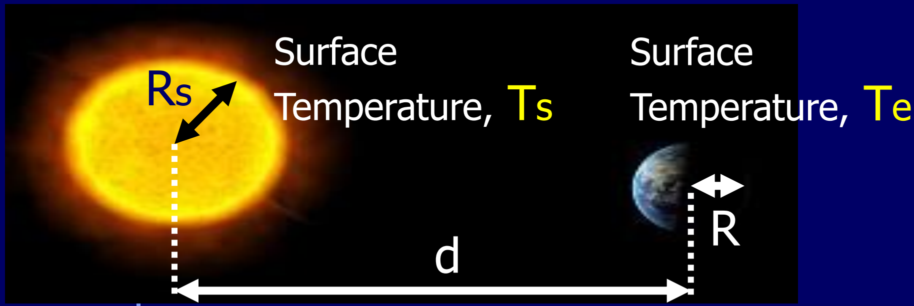
Note that the temperature of the air T_a near the ground is given by which yields a value for T_a lower than T_g.

$$\boxed{T_a = 288\,K}$$

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth (Plate Tectonics chapter) or another medium. What follows is a review of the way heat flows and is transferred, but applied to the atmosphere. Radiation is the transfer of energy between two objects by electromagnetic waves. Heat radiates from the ground into the lower atmosphere.

In **conduction**, heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate rapidly and collide with other nearby molecules, transferring their energy. In the atmosphere, conduction is more effective at lower altitudes where air density is higher; transfers heat upward to where the molecules are spread further apart or transfers heat laterally from a warmer to a cooler spot, where the molecules are moving less energetically.

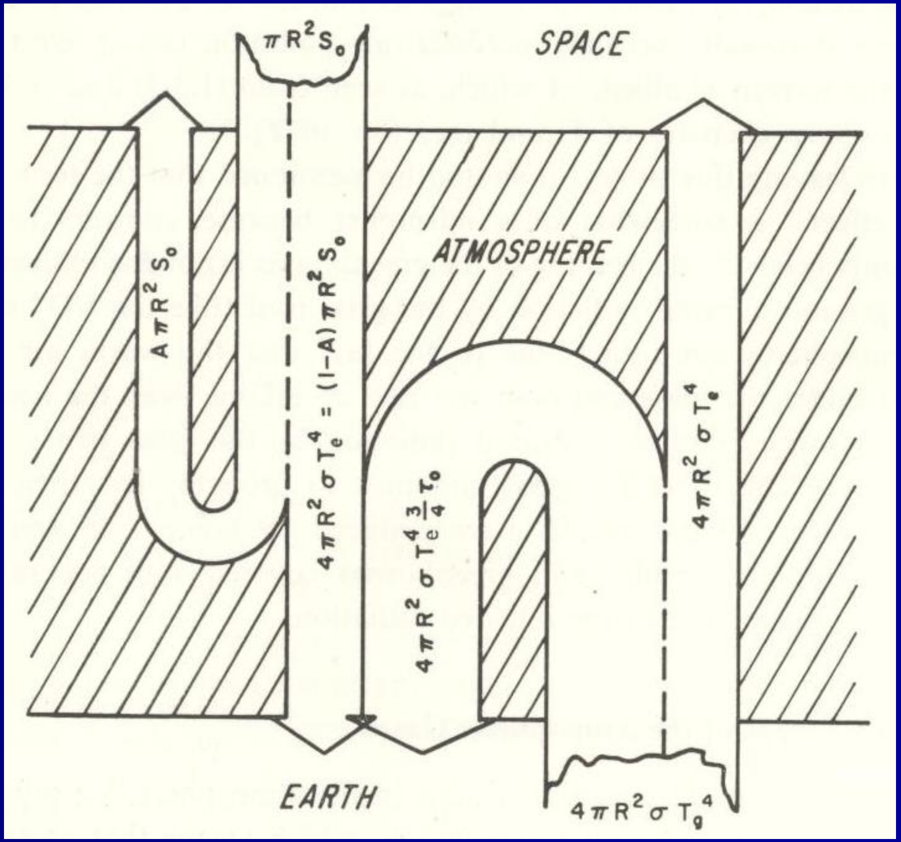


The temperature of the air T_a near the ground,

$$T_a = 288\,K$$

The discontinuity between T_g and T_a is in practice removed through conduction and convection and tends to lower the value of T_g obtained above.

This figure describes the balance between the radiation received and the radiation emitted by the Earth, including the green house effect.



A diagram showing the balance of heat, including the G.H.E. in the atmosphere of the Earth.

Planetary Atmospheres

Planetary Atmospheres

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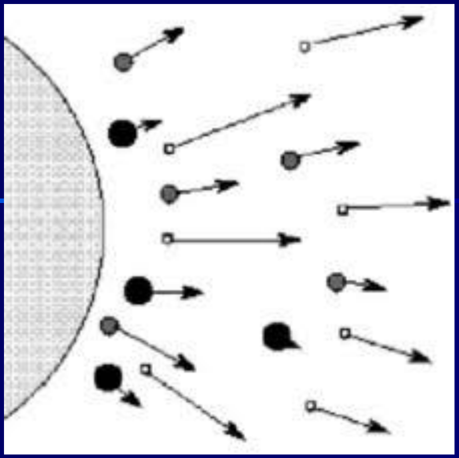
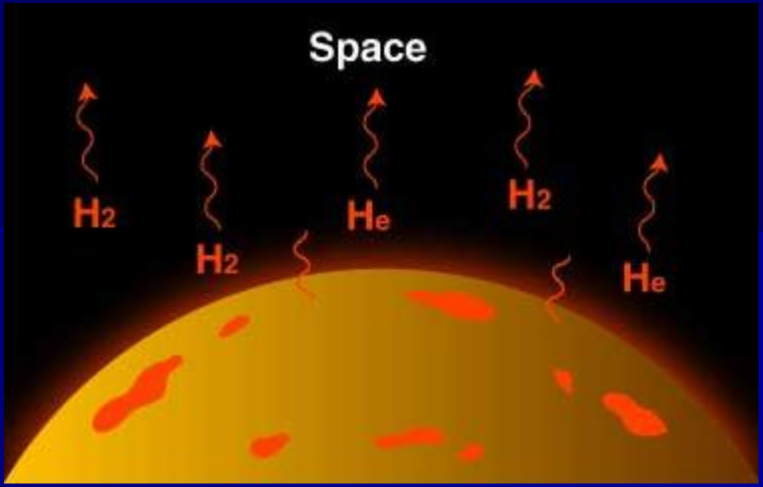
The Escape of the Atmospheric Gases





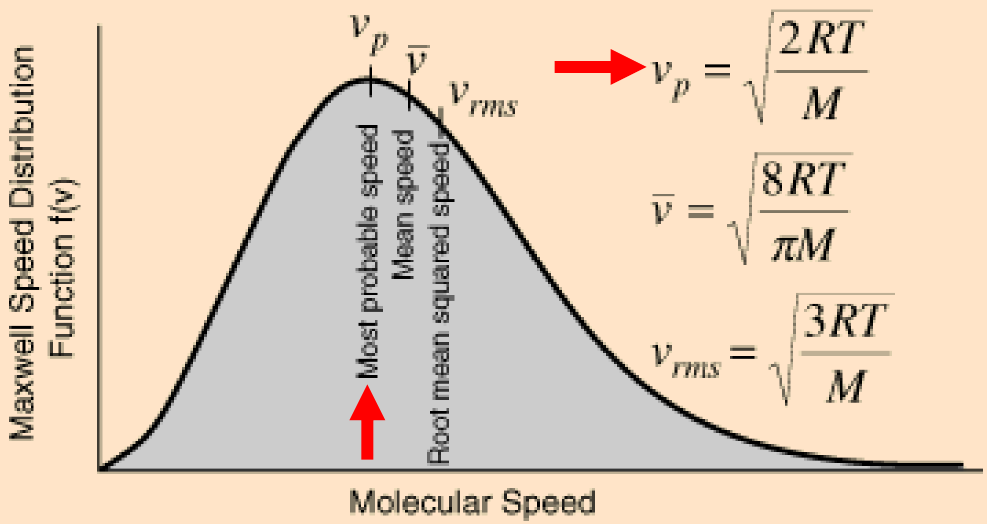
The kinetic theory of gasses shows that the particle velocities of a gas in a thermal equilibrium follow a Maxwellian Distribution, which in polar coordinates is given by the expression,

$$N\ f(V)dV\,d\Omega = 4\pi\,N\cdot\frac{e^{-\left(V/V_m\right)^2}}{\left(\pi V_m^2\right)^{3/2}}V^2 dV\,Sin\theta\,d\theta\,d\phi$$

Molecular Speed Calculation

The speed distribution for the molecules of an ideal gas is given by

$$f(v) = 4\pi\left[\frac{M}{2\pi RT}\right]^{\frac{3}{2}} v^2 \exp\left[\frac{-Mv^2}{2RT}\right]$$



$$v_p = \sqrt{\frac{2RT}{M}}$$

$$\bar{v} = \sqrt{\frac{8RT}{\pi M}}$$

$$v_{rms} = \sqrt{\frac{3RT}{M}}$$

The calculation of molecular speed depends upon the molecular mass and the temperature. For mass

m= 29 amu

M= 0.029 kg/mol

and temperature

T= 300 K

T= 26.850000 C

the three characteristic speeds may be calculated.

The nominal average molecular mass for dry air is 29 amu.

Most probable speed= v_p = 414.75819 m/s = 1493.1295 km/hr = 927.78766 mi/hr

Mean speed= $\bar{v}$ = 468.00451 m/s = 1684.8162 km/hr = 1046.8962 mi/hr

RMS speed= v_{rms} = 507.97297 m/s = 1828.7027 km/hr = 1136.3031 mi/hr

The Escape of the Atmospheric Gases

Maxwellian Distribution

$$f(V) = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} V^2 \cdot \exp\left(-MV^2/2RT\right)$$

The most probable speed (Vm)

The **most probable speed** is the speed associated with the highest point in the Maxwell distribution.

$$\frac{df(v)}{dv} = 0$$

$$\frac{d[f(V)]}{dV} = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} \frac{d}{dV}\left(V^2 \cdot \exp\left(-MV^2/2RT\right)\right) = 0$$

The Maximum/Minimum value is :

$$V = \left(\frac{2kT}{M}\right)^{1/2}$$

The Escape of the Atmospheric Gases

To find is it Maximum or Minimum : should be checked the second derivative of the **Maxwellian Distribution**

$$\frac{d^2[f(V)]}{dV^2} = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2}\frac{d}{dV}\left(\frac{d}{dV}\left(V^2\cdot\exp\left(-MV^2/2RT\right)\right)\right)$$

.

.

.

Then substitute $V = \left(\frac{2kT}{M}\right)^{1/2}$

$$\frac{d^2[f(V)]}{dV^2} = (-)ve$$

Then this V value should be the maximum value of the **Maxwellian Distribution**. This is called "The **most probable speed "** ,

$$V_m = \left(\frac{2kT}{M}\right)^{1/2}$$

The Kinetic Energy of a particle in the Earth's atmosphere whose mass is m,

$$= \frac{1}{2} m V_e^2$$

The Potential Energy of a particle on the surface of the Earth, $= -\dfrac{GMm}{R}$

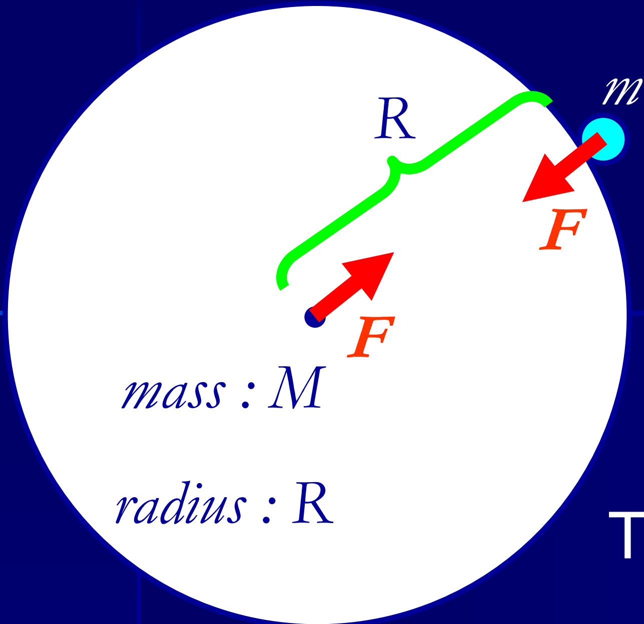
Where, M is the mass of the Earth and R is the Radius of the Earth.

Kinetic Energy exceeds Potential Energy, the particle can escape ;

$$\frac{1}{2} m V_e^2 = \frac{GMm}{R}$$

$$\therefore \quad V_e = \left(\frac{2GM}{R} \right)^{1/2}$$

Where, $GM = gR^2$ Proof : P.T.O



Using the Newton's Gravitational Law :

$$F = G\frac{Mm}{R^2}$$

Using the definition of the Gravitational field intensity :

$$g = \frac{F}{m} \rightarrow F = mg$$

Therefore, $G\dfrac{Mm}{R^2} = mg$ $\therefore$ $GM = gR^2$

Therefore, the Escape Velocity of a planet:

$$V_e = \left(\frac{2GM}{R}\right)^{1/2}$$

$$V_e = \left(\frac{2gR^2}{R}\right)^{1/2}$$

$$V_e = (2gR)^{1/2}$$

- For the Earth

$$g = 10\,ms^{-2}$$

$$R = 6.4\times10^{6}\,m$$

$$v_e = (2gR)^{\frac{1}{2}}$$

$$\therefore\ v_e = 11{,}200\,ms^{-1}$$

$$\therefore \quad \frac{V_e}{V_m} = \frac{(2gR)^{1/2}}{\left(\frac{2kT}{m}\right)^{1/2}} = \left(\frac{R}{kT/mg}\right)^{1/2} = \left(\frac{R}{H}\right)^{1/2}$$

Where, $H = kT/mg$

The ratio of $V_e : V_m$

$$\frac{V_e}{V_m} = \left(\frac{R}{H}\right)^{1/2}$$

$$\frac{V_e}{V_m} = \left(\frac{6400\,km}{8.7\,km}\right)^{1/2}$$

$$\frac{V_e}{V_m} = 27.6 \approx 28$$

$$V_e \approx 28\,V_m$$

Escape Velocity *Most Probable Velocity*

- For the Earth

$$H = kT/mg$$

$$H = \frac{(1.38\times10^{-23})(300)}{(4.8\times10-26)(9.81)}$$

$$H = 8.7\,km$$

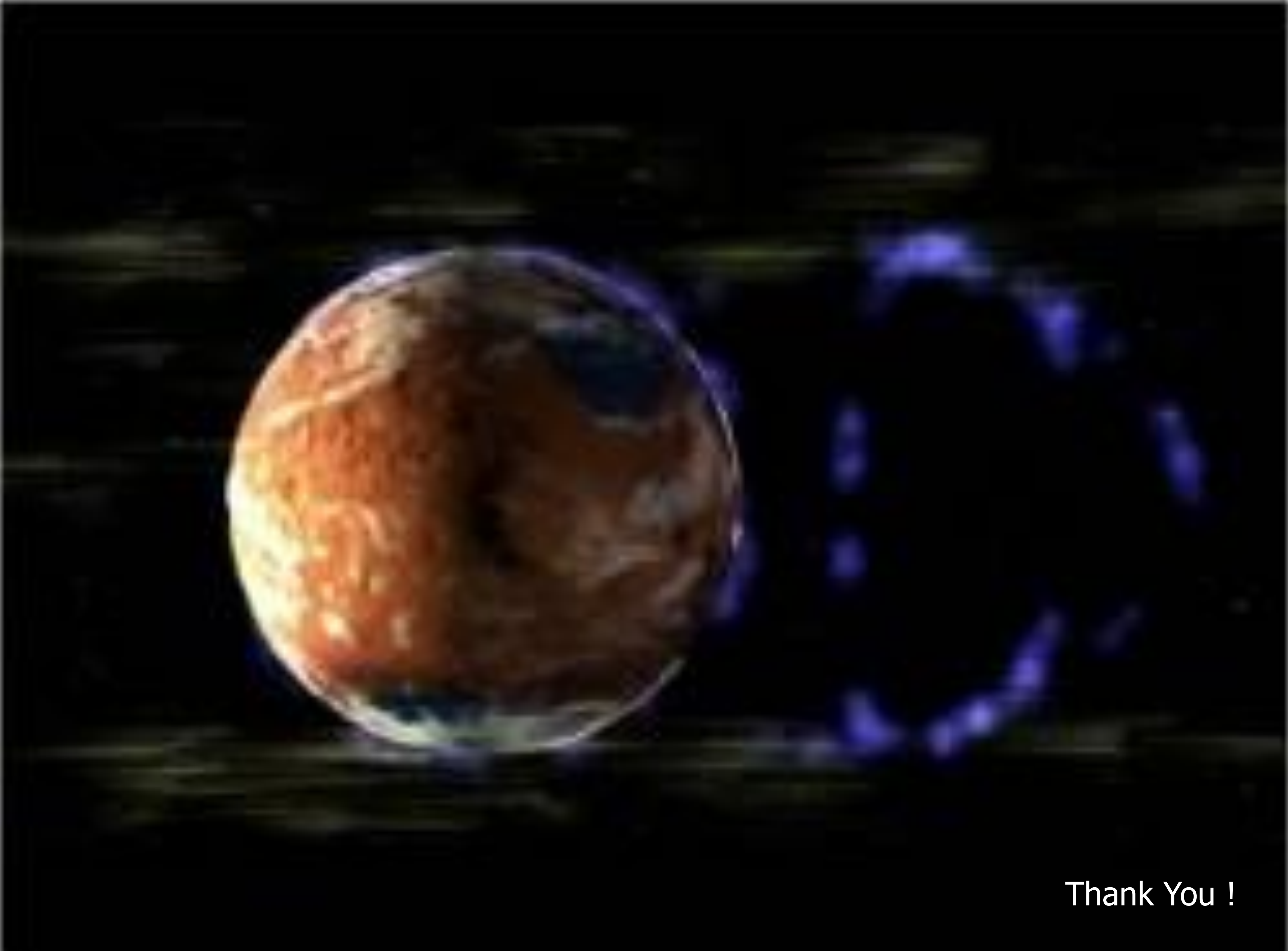
As a result, particles in the atmosphere can not escape to the interplanetary space!
(But this is not the only condition necessary for the particles to escape)

Planetary Atmospheres

Planetary Atmospheres

The Structure of the Terrestrial Atmosphere
The Temperature of the Neutral Atmosphere
The Escape of the Atmospheric Gases
The Atmospheres of the Earth

Atmosphere of Earth



Thank You !