Atmospheres: Earth vs. Mars

Overview

In this activity students will calculate the mass of the Earth and Mars atmospheres, then using compositional information will calculate the height of the Martian atmosphere. The principles of the calculation are outlined in full below.

Adaptation for student ability will depend on whether they i) know the values of constants and ii) are able to substitute equations.

Curriculum Links

Physics KS3-KS5 – pressure, force, SI units
Chemistry KS4-5 – Avogadro's law, Boltzmann's constant, molecular mass

Context

Mars has very different dimensions and physical properties compared to the Earth. It is almost half the Earth diameter (0.53 Earth diameter) and just a tenth of the Earth's mass. Mars has just 0.38 the Earth's surface gravity. The thickness of the Martian atmosphere is one of the reasons why it's surface is scarred by numerous impact craters. Earth's atmosphere is very thick, in excess of 700 km. It protects life on the surface from impact events and harmful radiation. Unlike the Earth, the Mars atmosphere it is too thin to ablate or destroy incoming asteroids and meteoroids.

Task 1: Earth Atmosphere

Atmospheric pressure is the force exerted by the mass of atmospheric gases per unit area of the surface.

$$\text{Pressure} = \frac{Force}{Area}$$

Substitute Force with an equation for force:

Force = mass x acceleration = mass x acceleration due to gravity

therefore:

pressure x area = mass x acceleration due to gravity

Question 1:

Assuming the Earth is a sphere:

Area = $4\pi r^2$

calculate the mass of the Earth atmosphere.

Question 2:

Show that the mass of the Earth atmosphere has the unit of kg.

Answer 1:
Using the following:
pressure = 1×10^5 Pa
radius of Earth = 6×10^6 m
g = 9.81 ms^{-1}

students substitute and rearrange the equation to solve for mass:

$$\text{mass} = \frac{pressure \times area}{g}$$

mass of the Earth atmosphere = 4.61×10^{18} kg

Answer 2:

equation:

$$\text{mass} = \frac{pressure \text{ x } area}{g}$$

substituting units:

$$\text{mass} = \frac{\frac{N}{m^2} \times m^2}{\frac{m}{s^2}}$$

conversion to SI units:

$$\text{mass} = \frac{\frac{kgm}{s^2 m^2} \times m^2 s^2}{m}$$

cancelling out:

mass = kg

Task 2: Mars Atmosphere

Question 3:

Now calculate the mass of the Mars atmosphere given that:

surface pressure = 600 Pa
radius = 3×10^6 m
g = 3.75 ms^{-2}

Question 4:

Which element of the equation influences the mass of the atmosphere the most.

Answer 3:

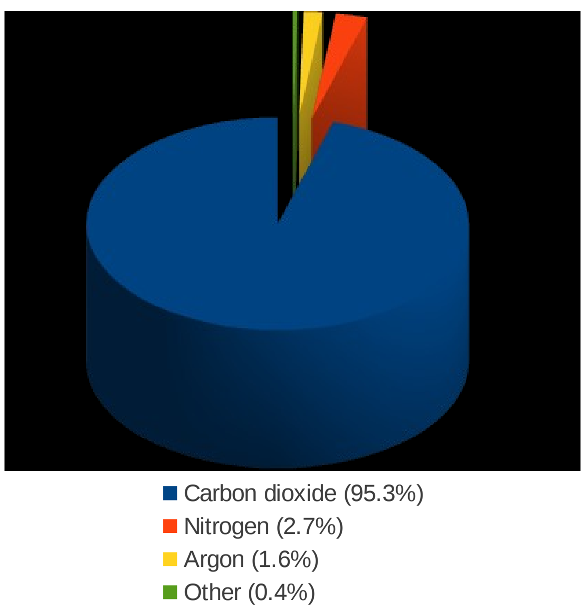
Mass of Mars atmosphere = 1.81×10^{16} kg

Answer 4:

The mass of Mars' atmosphere is two orders of magnitude smaller than that of the Earth. This calculation of mass is influenced by the surface pressure of Mars which is two orders of magnitude smaller than that of Earth.

Task 3:

The Earth atmosphere is in excess of 700 km thick. Calculate the thickness of the Mars atmosphere which is dominated by CO^2 (see image). Assume the Mars atmosphere is 100% CO^2 for the calculation.



Question 5:

Using Avogadro's number = 6.02×10^{23} calculate the mass of one CO_2 molecule **in Kg**

Answer 5:

mass of molecule = $\frac{molar\,mass}{Avogadro's\,number}$

mass of molecule = $\frac{44}{6.02\times10^{23}}$

mass of molecule = 7.31×10^{-23} g
mass of molecule = 7.31×10^{-26} kg

Question 6:
The properties of a planetary atmosphere can be described by scale height (H). This is the vertical distance above the surface at which the density or pressure of the atmosphere decreases by exactly 1/e (0.368).

H = $\frac{kT}{mg}$

where:
H = scale height (m)
T = Temperature (K)
m = Average mass of molecules (kg)
g = Acceleration of gravity (ms^{-2})
k = Boltzmann's Constant 1.38×10^{-23} (JK^{-1})

Using the mass of molecules calculated in Question 5 and *g* given in Question 3 calculate the height (km) of the Martian atmosphere assuming that the average Martian atmospheric temperature is 210K.

Answer 6:

H = $\frac{kT}{mg}$

H = $\frac{1.38\times10^{-23}\times270}{7.31\times10^{-26}\times3.75}$

H = 13599 m = 13.6 km