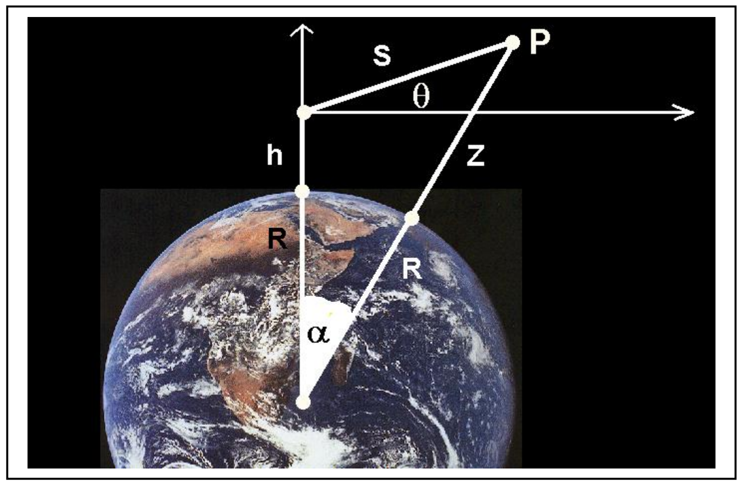
Atmospheric Shielding from Radiation II

The least expensive form of radiation shielding is a planetary atmosphere, but just how efficient is it? The walls of the International Space Station and the Space Shuttle provide substantial astronaut protection from space radiation, and have an equivalent thickness of 10 grams/cm^2 of aluminum, which has a density of 2.7 gm/cm^3. Compare this shielding to the spacesuits worn by Apollo astronauts of only 0.1 gm/cm^2. The atmosphere of Earth is a column of air with density of 0.0012 gm/cm^3, that is 100 kilometers tall. How much shielding does this provide at different altitudes above the ground?

In the previous problem 'Atmospheric Shielding from Radiation I' we defined a function that gives the length of the path from the radiation source to the measurement point located h above Earth's surface. To find the amount of shielding provided by the atmosphere, we have to multiply this length, by the density of the atmosphere along the path S. In this problem, we will assume that the atmosphere has a constant density of 0.0012 grams/cm^3, and see what the total shielding is along several specific directions defined by θ.



The formula for S is given by:

$$S(R,h,z,\theta) = \left((R + h)^2 \sin^2\theta \;+\; 2 R (z - h) + z^2 - h^2 \right)^{1/2} - (R + h) \sin\theta$$

Assume R = 6,378 kilometers.

Problem 1: What is the form of the function that gives the shielding for a direction A) straight overhead ($\theta = 90^0$) and B) at the horizon ($\theta = 0^0$), for a station at sea-level (h=0 kilometers)?

Problem 2: More than 90% of the atmosphere is present below an altitude of about 2 kilometers. If this is approximated as being uniform in height, what is the total shielding towards the zenith (overhead) and the horizon, if z = 2 kilometers?

Problem 3: The atmosphere of Mars is about 100 times less dense, and mostly resides below 1 kilometer in altitude. Re-calculate the answers to Problem 2, and compare the radiation dosage difference at the surface of each planet.

The formula for S is given by:

$$S(R,h,z,\theta) = \left((R + h)^2 \sin^2\theta \;+\; 2 R (z - h) + z^2 - h^2 \right)^{1/2} - (R + h) \sin \theta$$

Shielding $D(R,h,z,\theta) = 0.0012 \times S(R,h,z,\theta)$ in units of gm/cm^2 for S given in cm.

Problem 1: What is the form of the function that gives the shielding for A) a direction straight overhead ($\theta = 90^o$), and B) at the horizon ($\theta = 0^o$), for a station at sea-level (h=0 kilometers)?

Answer: A) $D = 0.0012 \times Z$ where Z is in centimeters.

B) $D(R,h,z,\theta) = 0.0012 \left(z^2 + 2 R z\right)^{1/2}$ where R and z are in centimeters.

Problem 2: More than 90% of the atmosphere is present below an altitude of about 2 kilometers. If this is approximated as being uniform in height, what is the total shielding towards the zenith (overhead) and the horizon, if z = 2 kilometers?

Answer:

A) $D = 0.0012\ gm/cm^3 \times 200{,}000\ cm = 240\ gm/cm^2$ for radiation entering from straight overhead.

B) Because $z << R$, $z^2 <<< 2Rz$ so

$$D = 0.0012 \times (2 R z)^{1/2}$$

$$= 0.0012 \times (2 \times (2 \times 10^5) \times (6.278 \times 10^6))^{1/2}$$

$$= 0.0012 \times 1.59 \times 10^6$$

$$= 1916\ gm/cm^2$$ for radiation entering from the horizon direction

Problem 3: The atmosphere of Mars is about 10 times less dense. Re-calculate the answers to Problem 2, and compare the radiation dosage difference at the surface of each planet.

Answer: For mars, R = 3,374 km, density = $0.00012\ gm/cm^3$ then from Problem 2:

A) $D = 0.00012\ gm/cm^3 \times 100{,}000\ cm = 12\ gm/cm^2$

B) $D = 0.00012 \times (2 R z)^{1/2}$

$= 0.00012 \times (2 \times (1 \times 10^5) \times (3.374 \times 10^6))^{1/2}$

$= 0.00012\ gm/cm^3 \times 8.2 \times 10^5\ cm$

$= 98\ gm/cm^2$

The minimum radiation shielding comes from directions above your head that pass through the least amount of atmosphere. The amount of radiation shielding at the surface of Mars is $(240\ gm/cm^2) / (12\ gm/cm^2) = 20$ times less than on Earth. That means that radiation dosages at the surface of Mars would be about 20 times higher than on Earth's surface. Instead of 27 mRems/year, which is typical of the cosmic ray background on Earth's surface, you would receive about $27 \times 20 = 560$ mRems/year on Mars. Compare this with 370 mRems/year as the average human dosage on Earth from all sources.

In the next problem 'Atmospheric Shielding from Radiation III' we will calculate this shielding more exactly.