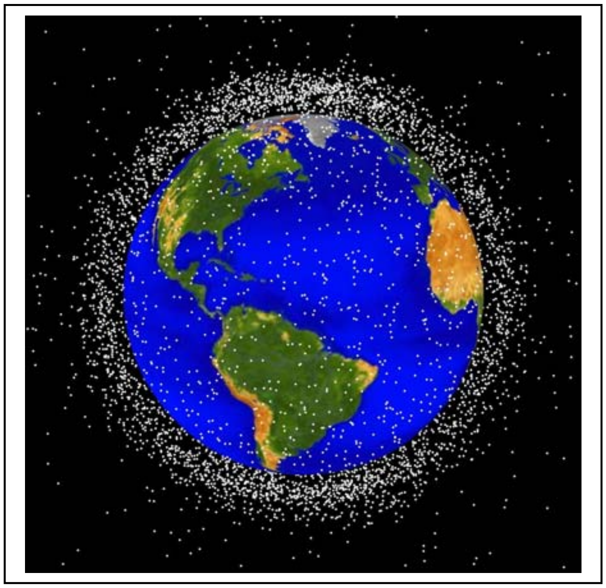

We live at the bottom of a deep 'gravity well' that takes an enormous amount of energy to climb out of. The figure shows the locations of 12,000 currently in Low Earth Orbit (LEO). To reach any altitude above sea level, we have to work against gravity. The higher we want to climb, the more energy we need to use to reach that altitude.

We can measure this energy in terms of the number of joules per kilogram (J/kg) that is needed to reach an elevation of h meters. The formula is given very simply by

$$E = 9.8\ h \quad \text{J/kg}$$

**Problem 1** - A mountain climber hikes from sea level to the top of Mt Everest, which has an altitude of 8,848 meters. A) How many Joules/kg will he need for the trip? B) If his total mass is 75 kg, how many Joules of energy will he have to expend to reach the summit?

**Problem 2** - The Ares 1-X rocket was launched on Wednesday, October 28 at Cape Canaveral. If the payload reached a maximum altitude of 45 kilometers, A) how many megaJoules/kg were needed for the payload to reach this altitude? B) If the payload mass was 5,000 kg, how many megaJoules were required?

**Problem 3** - At what altitudes will the mountain climber and the Ares 1-X need to expend the same number of Joules/kg?

**Problem 4** - How many megaJoules/kg will the Ares 1-X need to expend to reach Low Earth Orbit at an altitude of 200 miles? (1 mile = 1.62 kilometers).

**Problem 5** - In terms of megaJoules/kg, by what factor is the Ares 1-X energy requirement higher to get into LEO than to reach an altitude of 45 kilometers?

**Problem 1** - A mountain climber hikes from sea level to the top of Mt Everest, which has an altitude of 8,848 meters. A) How many Joules/kg will he need for the trip? B) If his total mass is 75 kg, how many Joules of energy will he have to expend to reach the summit?

Answer; A) E = 9.8 x 8848 = 87,000 J/kg.

B) E = 87,000 J/kg x (75 kg) = 6,500,000 Joules.

**Problem 2** - The Ares 1-X rocket was launched on Wednesday, October 28 at Cape Canaveral. If the payload reached a maximum altitude of 45 kilometers, A) how many megaJoules/kg were needed for the payload to reach this altitude? B) If the payload mass was 5,000 kg, how many megaJoules were required?

Answer: A) E = 9.8 x 45 km x (1000 m/km) = 440,000 J/kg.
B) E = 440,000 J/kg x (5,000 kg)
= 2,200,000,000 Joules = 2,200 megaJoules.

**Problem 3** - At what altitudes will the mountain climber and the Ares 1-X need to expend the same number of Joules/kg?

Answer: Because E = 9.8 x h and does not depend on the mass of the body, the mountain climber and the Ares 1-X payload will need the SAME number of Joules/kg to reach all elevations that they have in common up to 8,848 meters.

**Problem 4** - How many megaJoules/kg will the Ares 1-X need to expend to reach Low Earth Orbit at an altitude of 200 miles? (1 mile = 1.62 kilometers).

Answer: First we have to convert 200 miles to meters:

200 miles x (1.61 km/mile) x (1000 meters/1 km) = 322,000 meters.

Then E = 9.8 x (322,000) = 3,200,000 Joules/kg or 3.2 megaJoules/kg.

**Problem 5** - In terms of megaJoules/kg, by what factor is the energy requirement for Ares 1-X higher to get into LEO than to reach an altitude of 45 kilometers?

Answer: To reach 45 km requires 0.44 megaJoules/kg while for LEO it requires 3.2 megaJoules/kg so the energy factor per kilogram of payload mass is 3.2/0.44 = 7.3 times higher.

Teacher Note: The unit Joules/kg is also called the 'energy density'. Different fuels have different energy densities. A peanut butter and jelly sandwich (500 calories and 0.1 kg) has E = 21,000 Joules/kg, while solid rocket fuel has E = 5 megaJoules/kg!