FACS - FORTEST meetings 2002 - 2003

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Approx. 220 pages

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Question:

Suppose you were standing on an asteroid and ran fast or jumped in the air. If the asteroid was small enough, you would achieve escape velocity and fly off into space. How small does the asteroid have to be for this to happen? A diameter of 10 km? 5 km? 1 km? If it was smaller still, you would be in danger of flying off accidentally by taking too springy a step. How small?

Some data:

> The diameter of the earth is 12,756 km, radius therefore $6.378 \cdot 10^3$ km.
>
> The mass of the earth is $5.97 \cdot 10^{24}$ kg
>
> The acceleration due to gravity on the surface of the earth is 9.8 m/sec^2.
>
> Most smaller planetary bodies seem to have a density of about 0.6 times that of earth, i.e. about 3,300 kg/m^3

Answer

All bodies at a given distance from the earth fall with the same acceleration. Therefore the gravitational force exerted by a planet or asteroid such as the earth on a body is proportional to the mass of the body (force = mass times acceleration). By symmetry, the force exerted by gravity between two bodies is proportional to the product of their masses. The inverse square law applies to any force between two bodies that originates in them. So the force exerted by gravity between two bodies of masses M and m at a distance d apart is $GMmd^{-2}$, where G is a constant.

A body on the surface of the earth experiences an acceleration of 9.8 m/sec^2 = GMd^{-2}

Here $d = 6.378 \cdot 10^3$ km, so:

$$9.8 \text{ m/sec}^2 = GMd^{-2}$$

$$= G \cdot 5.97 \cdot 10^{24} \text{ kg} / 6.378^2 \cdot 10^6 \text{ km}^2$$

$$= G \cdot 1.47 \cdot 10^{11} \text{ kg/m}^2$$

Therefore $G = 9.8 \cdot 10^{-11} / 1.47 \text{ m}^3/\text{sec}^2 \text{ kg} = 6.68 \cdot 10^{-11} \text{ m}^3/\text{sec}^2 \text{ kg}$ (an interesting physical dimension)

The energy needed for a body of mass m to escape from a planetoid of mass M is the potential energy of the body at an infinite distance from the planetoid:

$$= \int_r^\infty GMmx^{-2}dx$$

$$= GMmr^{-1} \text{ m}^2 \text{ kg/sec}^2$$

where r is the radius of the planetoid.

It might be difficult to run on a very small planetoid, but at least one should be able to do a vertical standing jump. On the earth one can take such a jump that raises one's centre of gravity by perhaps half a metre. One might accidentally take a springing step that raised one's centre of gravity 0.25 metre. These would represent an energy (force times distance, i.e. acceleration times mass times distance) of:

$$9.8 \cdot 0.5\, m = 4.9\, m \text{ kg m}^2 / \text{sec}^2$$