Forces, Energy and Power

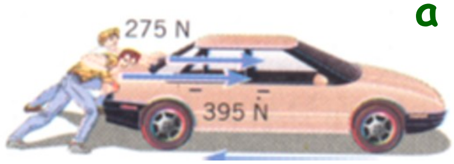
- **force: acts on body**
- **energy: work done on body or capacity to do work**
- **power: work done per time**

Newton's three laws of motion:

1. An object continues in a state of rest or in a state of motion at a constant speed along a straight line, unless compelled to change that state by net force.
2. When a net external force, F, acts on an object of mass, m, the acceleration, a, that results is proportional to the force and has a magnitude that is inversely proportional to the mass. The direction of the acceleration is the same as the direction of the force.
3. Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body.

Example: 2 Guys Pushing a Car

a force acting on a body accelerates it



Force: F

F

Distance: D

F proportional to:

mass m
acceleration a

$F = m \times a$

Work W proportional to:

force F
distance D

$W = F \times D$

Power P proportional to:

work W
inverse of time t

$P = W/t$

Example: 2 Guys Pushing a Car

Power P proportional to:

work W
inverse of time t

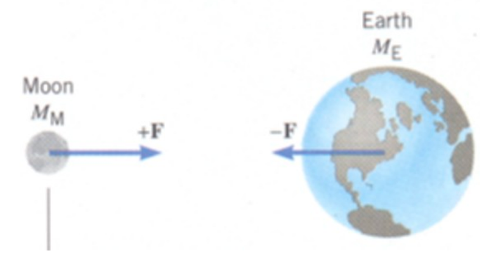
$$P = W/t$$

If same work is done in less time, then the process required more power. E.g. push a car in 10 min over distance D requires more power than doing this in 20 min.

Gravitational Force

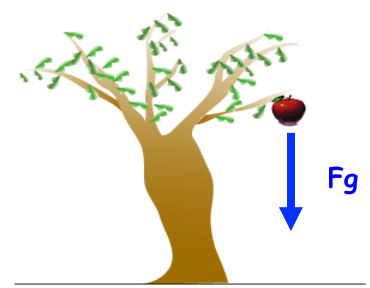
$F = m \times a$

attraction of bodies due to their mass



For bodies that are small compared to Earth and are close to Earth's surface, compared to its radius (6371 km), we can assume that g is constant.

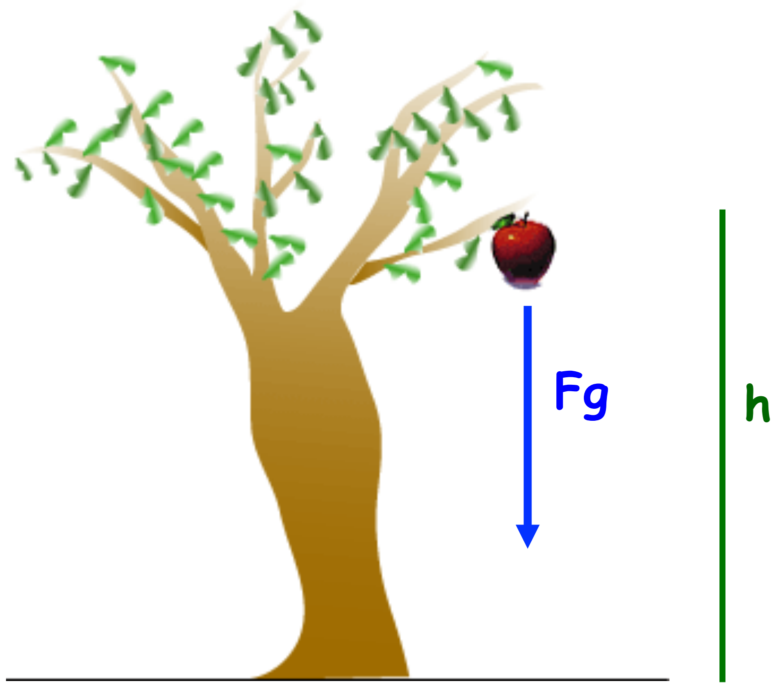
gravitational acceleration g



$Fg = m \times g$

Gravitational Force and Potential Energy

Example: Isaak Newton's Apple



When the apple hangs on the tree, it has potential energy that can be used up and transferred into another type of energy.

$$Fg = m \times g$$

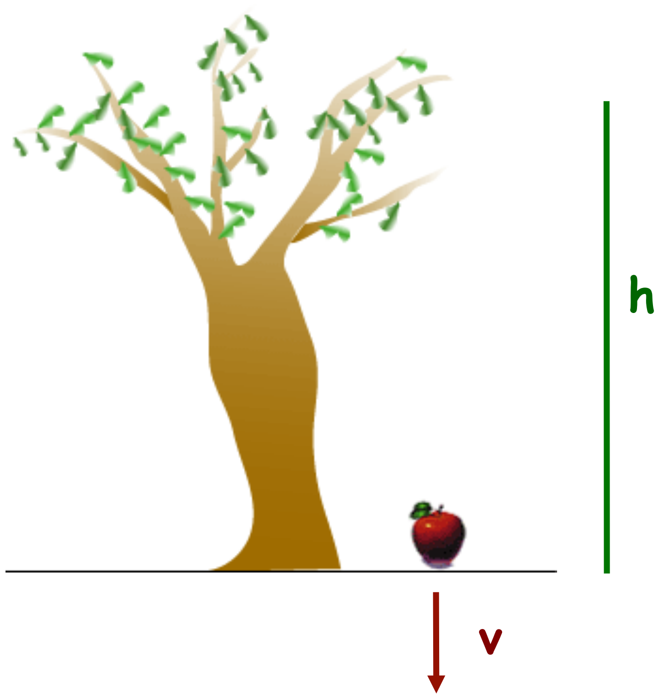
Epot proportional to:

mass m
gravitational force Fg
height h

$$\begin{aligned} Epot &= Fg \times h \\ &= m \times g \times h \end{aligned}$$

Gravitational Force, Potential Energy and Kinetic Energy

Example: Isaak Newton's Apple



$$E_{pot} = m \times g \times h$$

$h = 0$

$E_{pot} = 0$

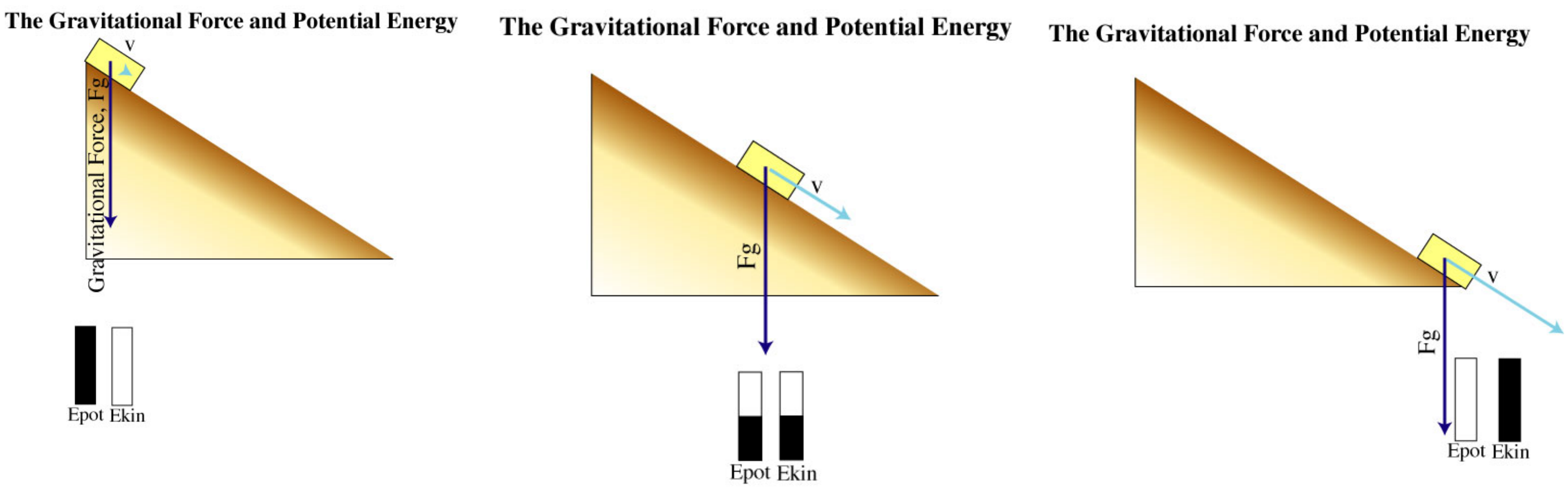
$$E_{kin} = 1/2\ m \times v^2$$

When the apple falls, it looses potential energy and gains kinetic energy. When it reached the ground, it lost all its potential energy.

Just before it hits the ground, it has only kinetic energy. When it hits the ground, this energy is used up to deform the apple.

Exchange of Potential and Kinetic Energy

energy can be transferred from one type to another e.g. when a mass slides down a slope

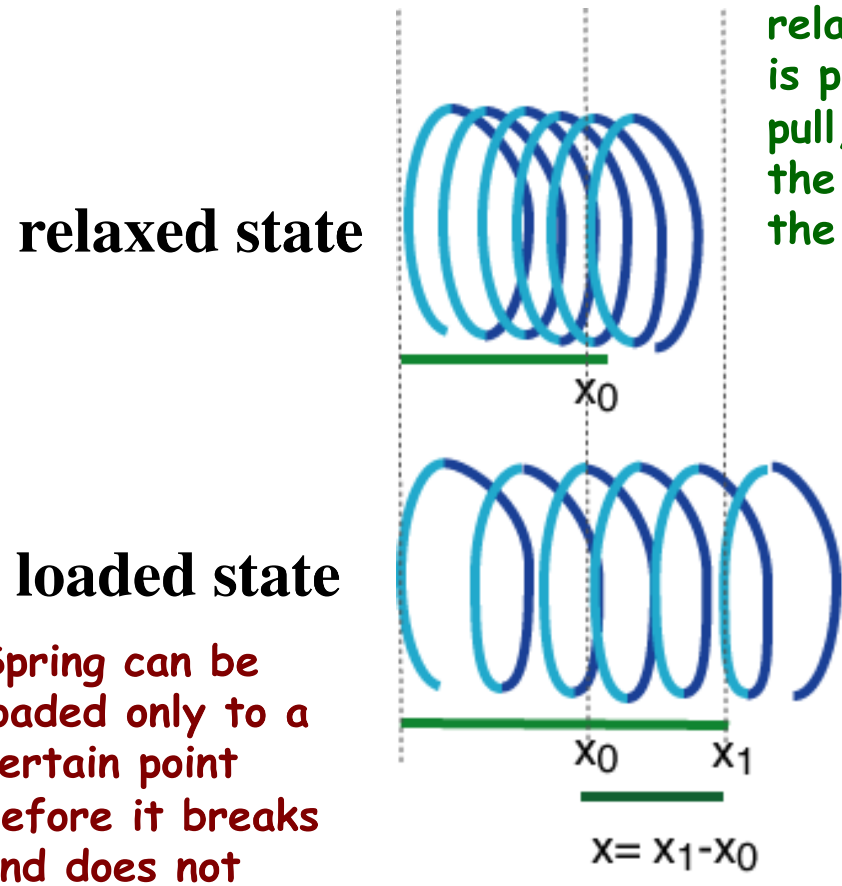


$$Epot = m \times g \times h$$

This example ignores friction between the mass and the slope.
If friction is included, some of the potential energy is lost to heat for the moving mass to overcome the friction.

Elastic Potential Energy in a Loaded Spring

When you pull on a spring that was initially relaxed, you use a force to load it. This force is proportional to the distance over which you pull, and the spring constant, k,that describes the stiffness of the spring (or its resistance to the pull).



$$Fg = k \times x$$

with:
k: spring constant k
x: distance pulled

$$Epot = 1/2\ k \times x^2$$

Spring can be loaded only to a certain point before it breaks and does not behave elastically anymore.

Though the math is more complex,the same principle applies to elastic media that are bent without breaking them (e.g. a wooden stick, lithospheric plate). When the medium breaks, Epot is released.

Elastic Potential Energy in a Lithospheric Plate

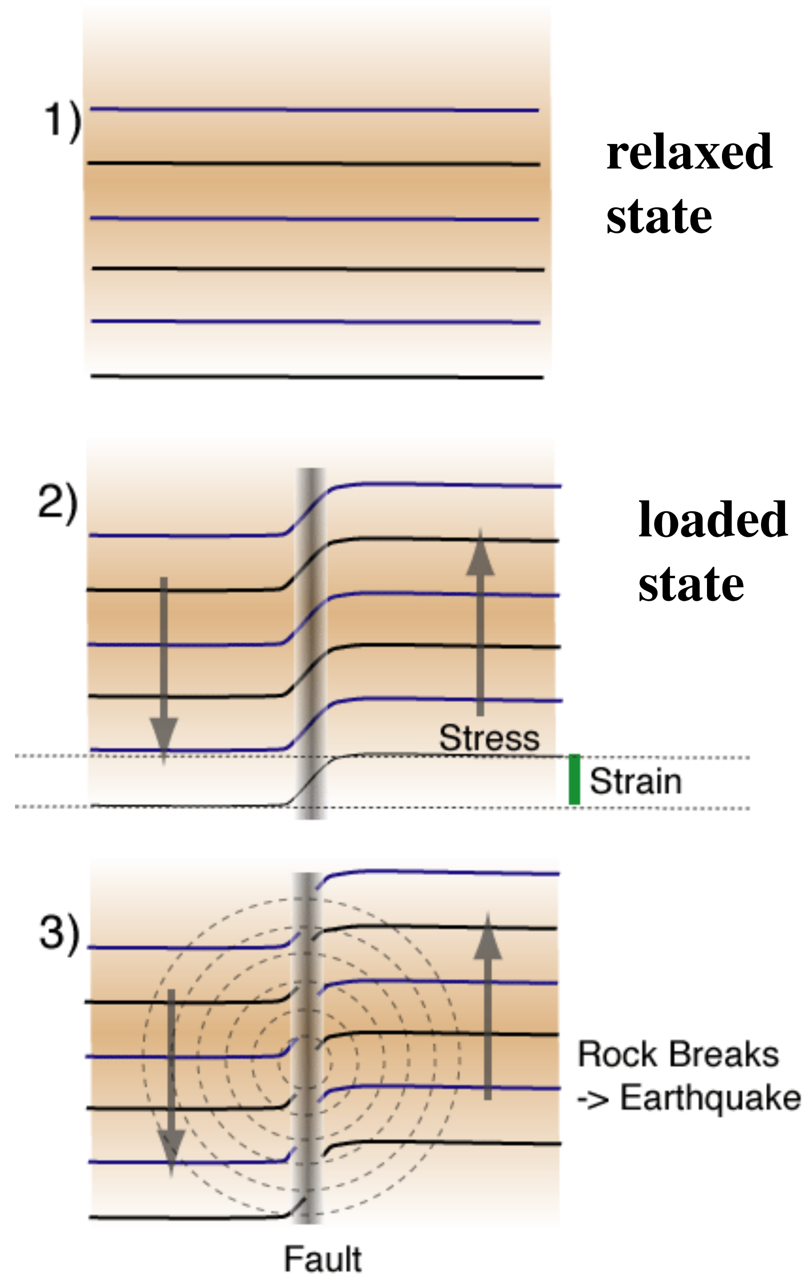
In earthquake science, we use the words stress and strain instead of force and distance pulled (deformation).
But the analogy to a loaded spring is obvious.

force <-> stress

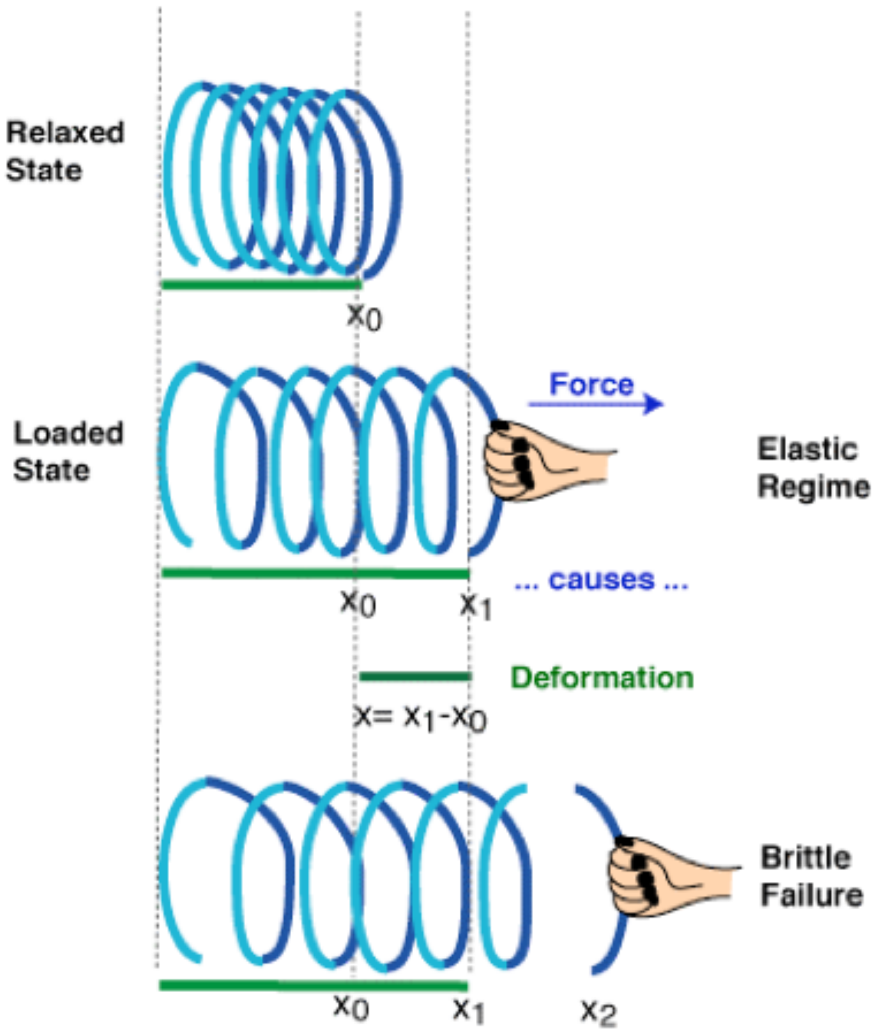
deformation <-> strain

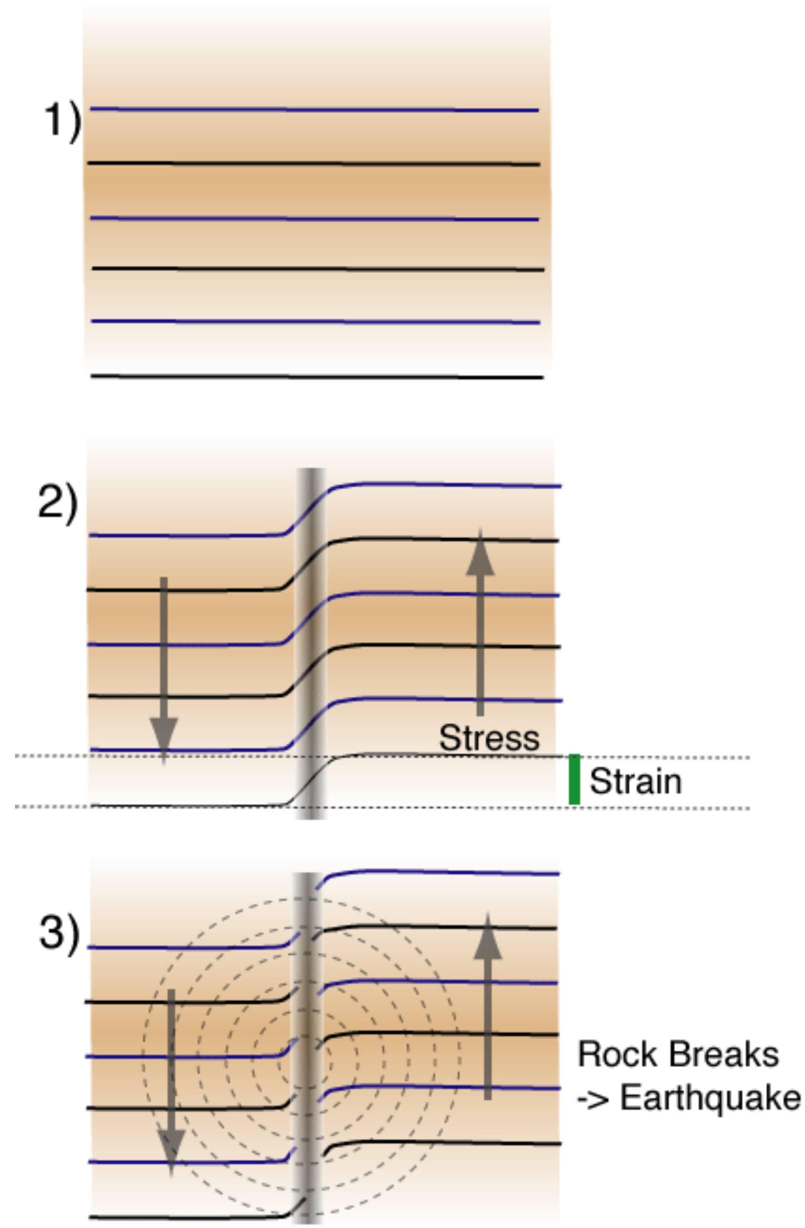
strain is a result of stress

The potential energy accumulated during the loading is released in an earthquake. This energy is used when you feel the shaking (Ekin) and structures are damaged or destroyed.



Properties of a Material





Gravitation

attraction of bodies due to their mass

attracting force:
gravitational force Fg

M_E: Earth's Mass
M_M: Moon's Mass
d: Earth-Moon distance
G: Gravitational constant

If two bodies have about the same mass (e.g. Earth and Moon) then the gravitational force is more complicated:

$$Fg = \frac{G \times M_E \times M_M}{d^2}$$

If we consider a force with respect to Earth, then we can simplify by defining the gravitational acceleration, g, as:

$$g = \frac{G \times M_E}{d^2}$$

m: mass of attracted body
g: Earth's gravitational acceleration

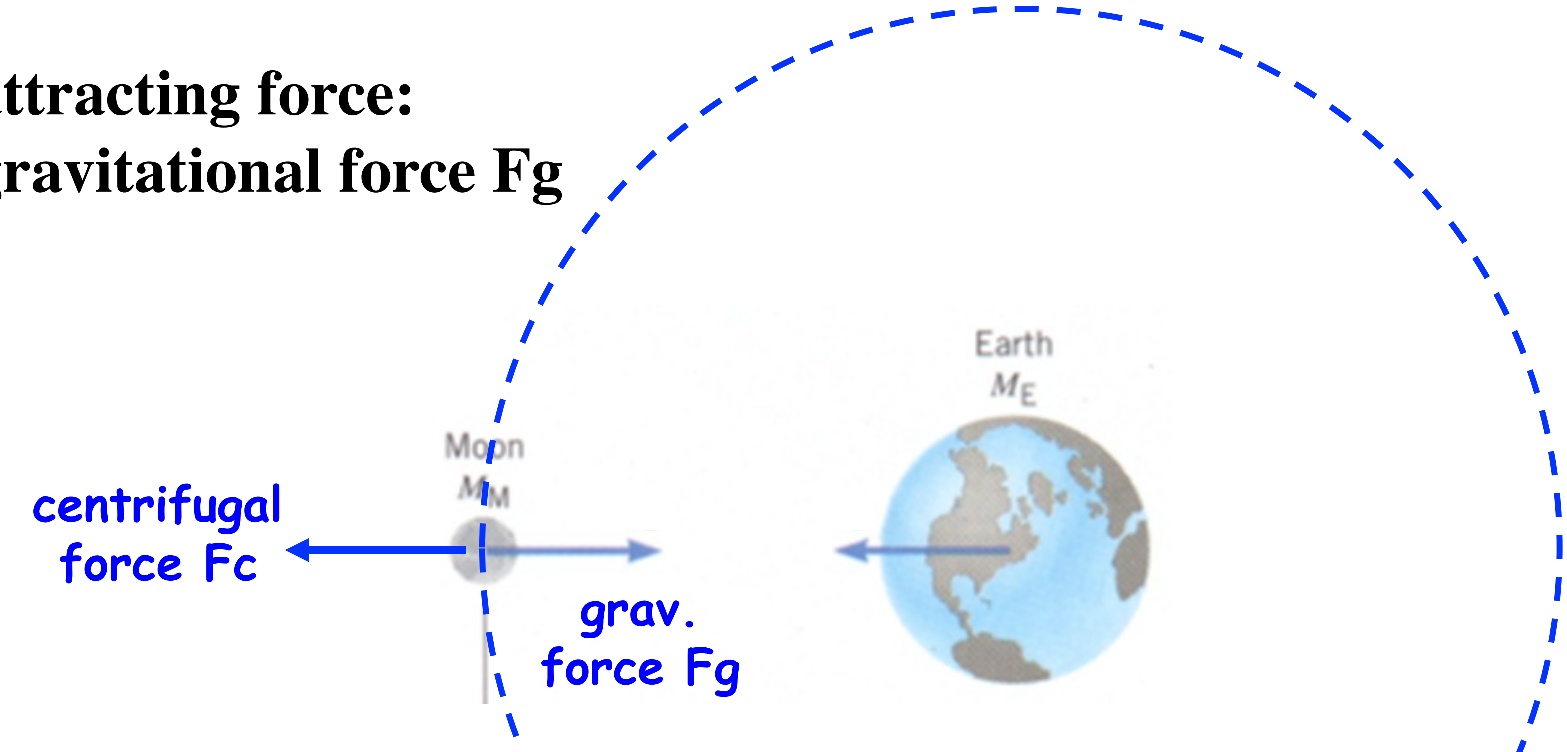
Now we have an equation very similar to that on page 1, but g depends on the distance, d, between the two bodies:

$$Fg = m \times g$$

Gravitation

attraction of bodies due to their mass

attracting force:
gravitational force Fg



Q: If Earth pulls with force Fg on the Moon, why does the Moon not smash into Earth?

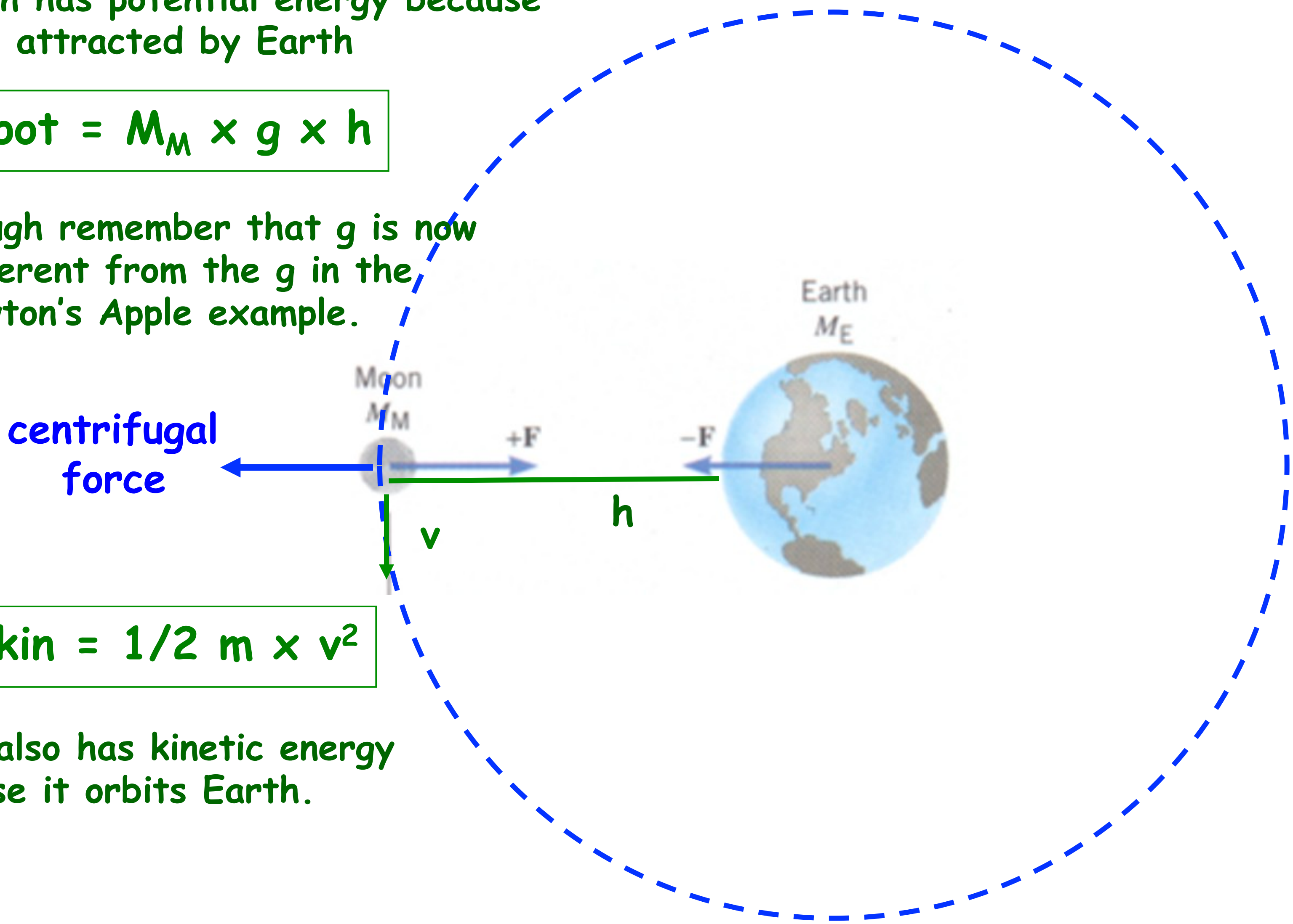
A: Because the Moon orbits Earth. The orbiting motion causes an acceleration and thereby a force (centrifugal force) that counteracts Earth's attraction.

The Moon and Earth: Different Types of Energy

Moon has potential energy because it is attracted by Earth

$$Epot = M_M \times g \times h$$

though remember that g is now different from the g in the Newton's Apple example.

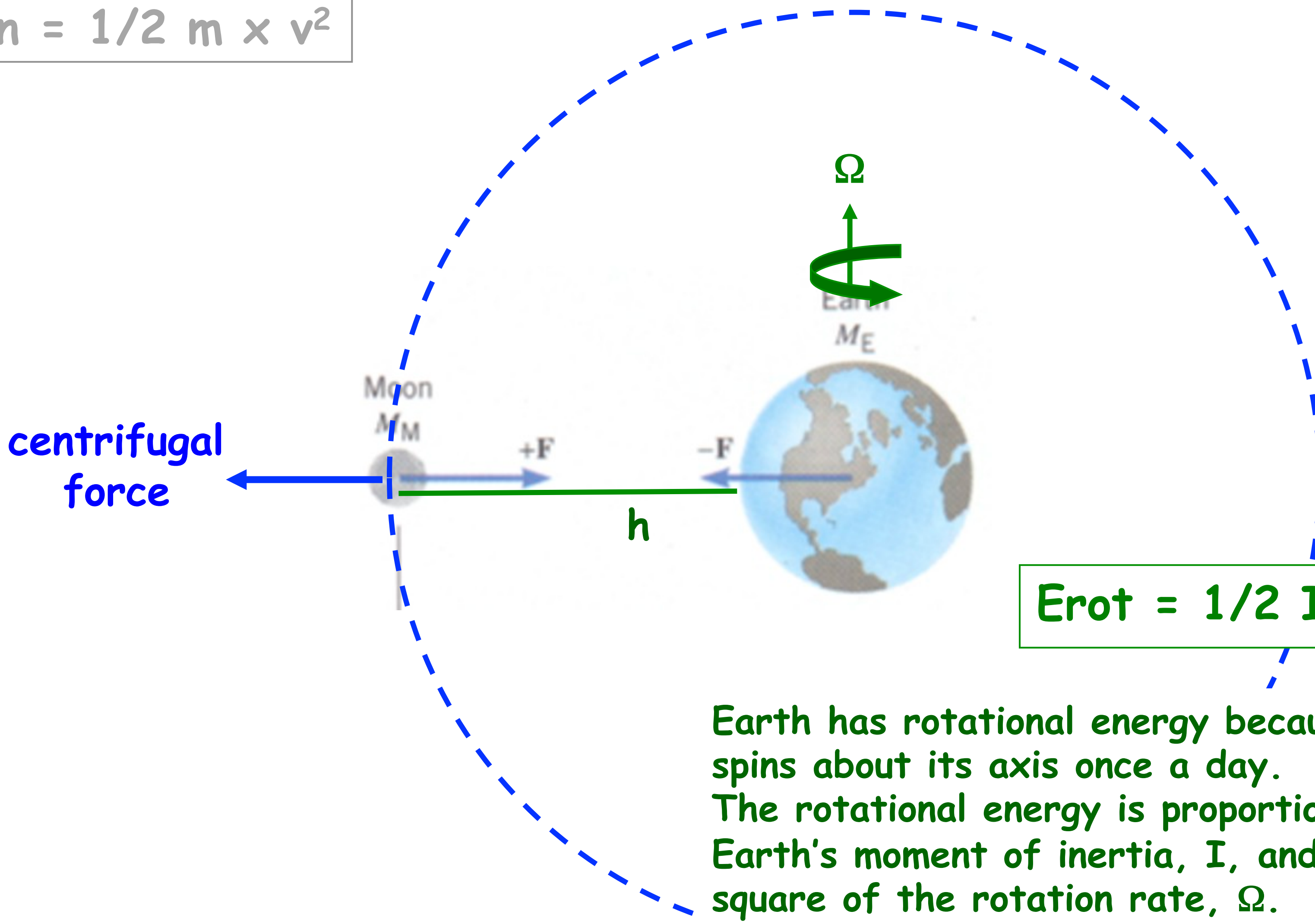


$$Ekin = 1/2\ m \times v^2$$

Moon also has kinetic energy because it orbits Earth.

The Moon and Earth: Different Types of Energy

$E_{kin} = 1/2\ m \times v^2$



$E_{rot} = 1/2\ I \times \Omega^2$

Earth has rotational energy because it spins about its axis once a day.
The rotational energy is proportional to Earth's moment of inertia, I, and to the square of the rotation rate, Ω.