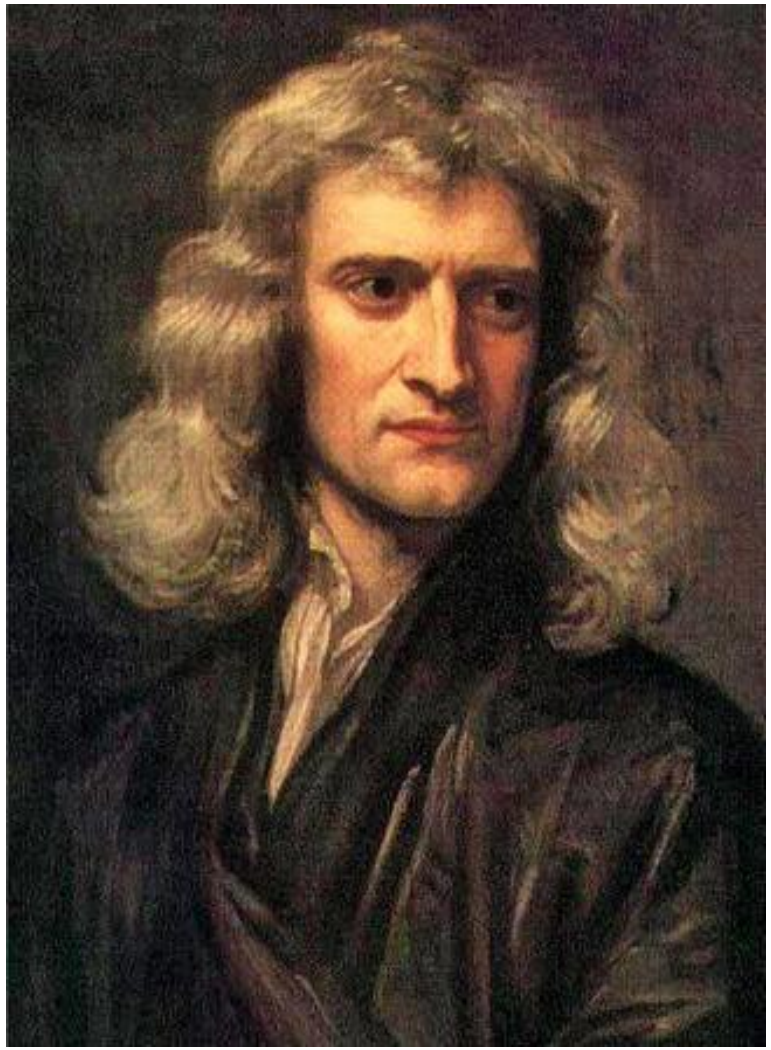
Isaac Newton and Orbital Motion

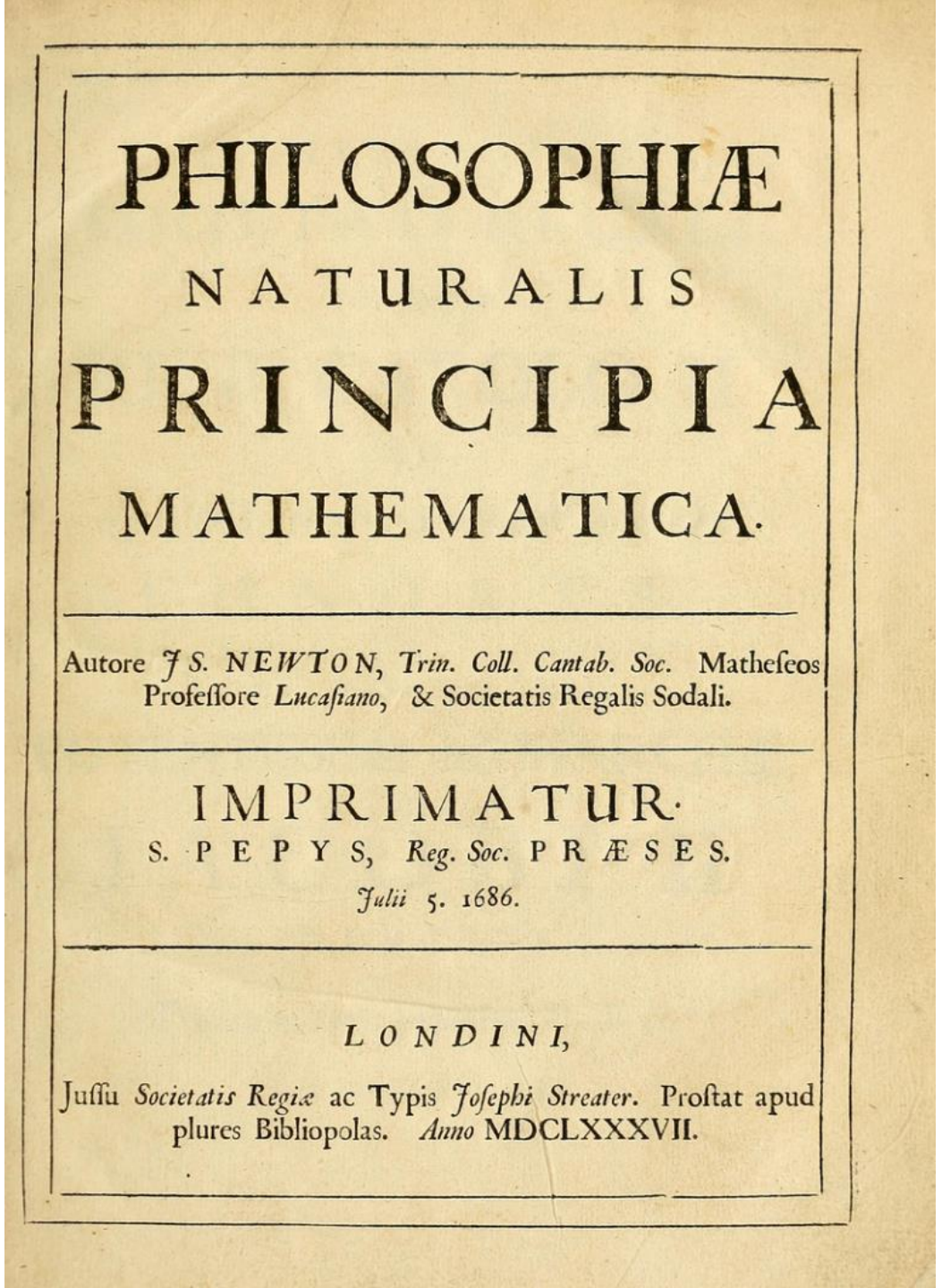
By the time Isaac Newton was born, modern astronomy had been 100 years in development, laying the foundations that we still use today.

Isaac Newton created new ***physical*** interpretations to the ***mathematical*** descriptions of astronomy made by Copernicus, Kepler, and Galileo.



Newton and “The Principia”

- Contains all 3 laws of motion, the law of gravity,
and multiple concepts that
will define physics for centuries
to come, including today.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON, Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater.* Proſtat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Newton in Inspired (triggered) by Descartes Philosophy

- A relatively recently translated to English work

De Gravitatione et aequipondio fluidorum (“On the gravity and equilibrium of fluids”) was written two years before the Principia was written as a reply to Descartes.
Since Descartes formulated the law of inertia, the concept of Force as we know it is also due to him.

Rene Descartes, by Frans Hal

Isaac Newton and Orbital Motion

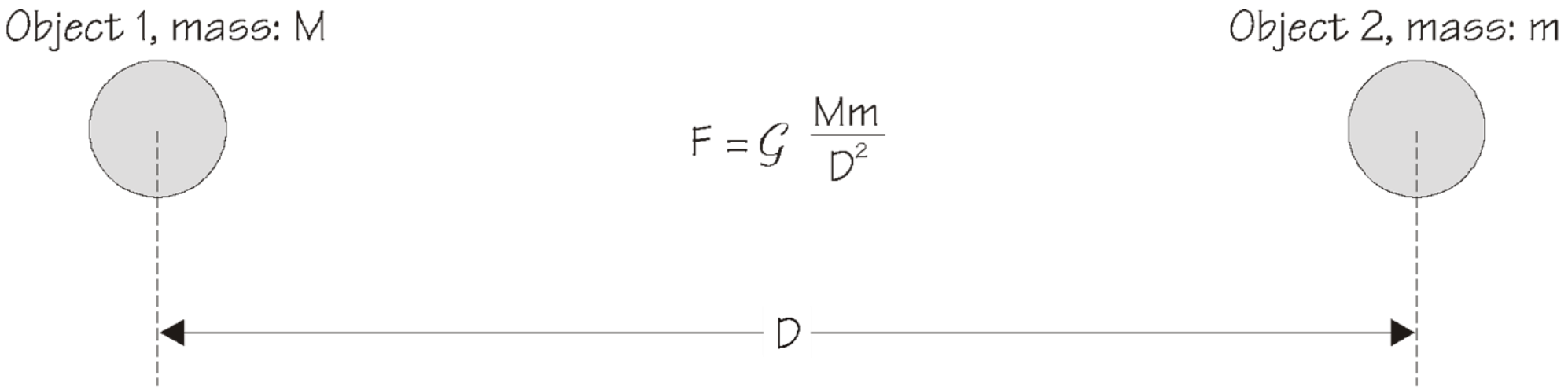
Newton developed the **universal law of gravitation**, a short equation (see right) which says that there is a force between any two masses.

$$F = G\frac{Mm}{r^2}$$

The **acceleration of gravity** of the Earth, Moon, or other astronomical body does not depend on the mass of the dropped object. Galileo had already determined that, and Apollo 15 showed it on the moon with a hammer and a feather!

Isaac Newton and Orbital Motion

The only requirement for gravity to act on an object is that it has mass (i.e. it physically exists) and there is another object with mass anywhere in the universe.



$$\text{Force of Gravity} = (\text{Gravitational Constant}) \frac{(\text{Mass of object 1}) \times (\text{Mass of object 2})}{(\text{Distance between centers})^2}$$

Newton's Law and Gravity

Pause-and-Think MC Question:

Which of the following would cause the force on the Moon by Earth to increase by the largest amount?

A) double the mass of the Moon.

B) double the mass of Earth.

C) move the moon two times closer to Earth.

D) None of the above would change the force.

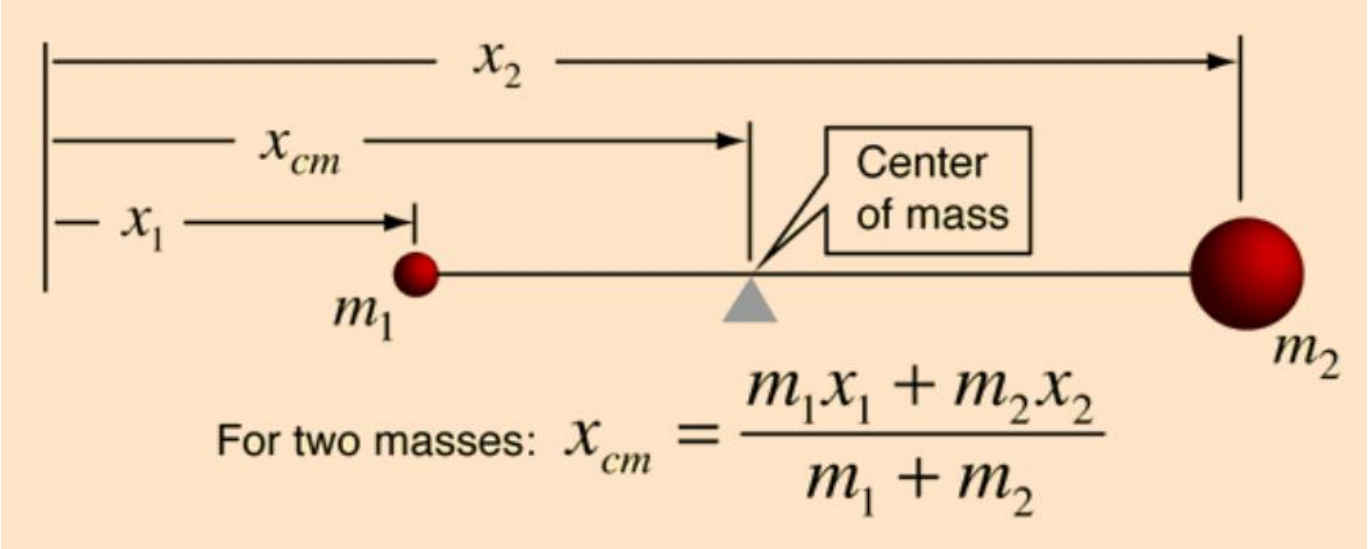
Center of Mass

- Gravitational Force

$$\vec{F} = -\frac{Gm_1m_2}{r^2}\,\hat{r}$$

- Center of Mass

$$\overrightarrow{R_{CM}} = \frac{m_1\overrightarrow{r_1} + \overrightarrow{m_2r_2}}{m_1 + m_2}$$



Newton's formulation of Kepler's 3rd law

We start by equating the gravitational specific force to the acceleration of the object (Newton invents the term "centripetal acceleration"):

$$\omega = \frac{v_t^2}{r} = \frac{\theta}{\Delta t}$$

$$\frac{Gm_1}{a^2} = a\omega^2$$

$$\frac{Gm_1}{a^3} = \omega^2$$

$$\frac{T^2}{(2\pi)^2} = \frac{a^3}{Gm_1}$$

Although, if we consider center of mass…

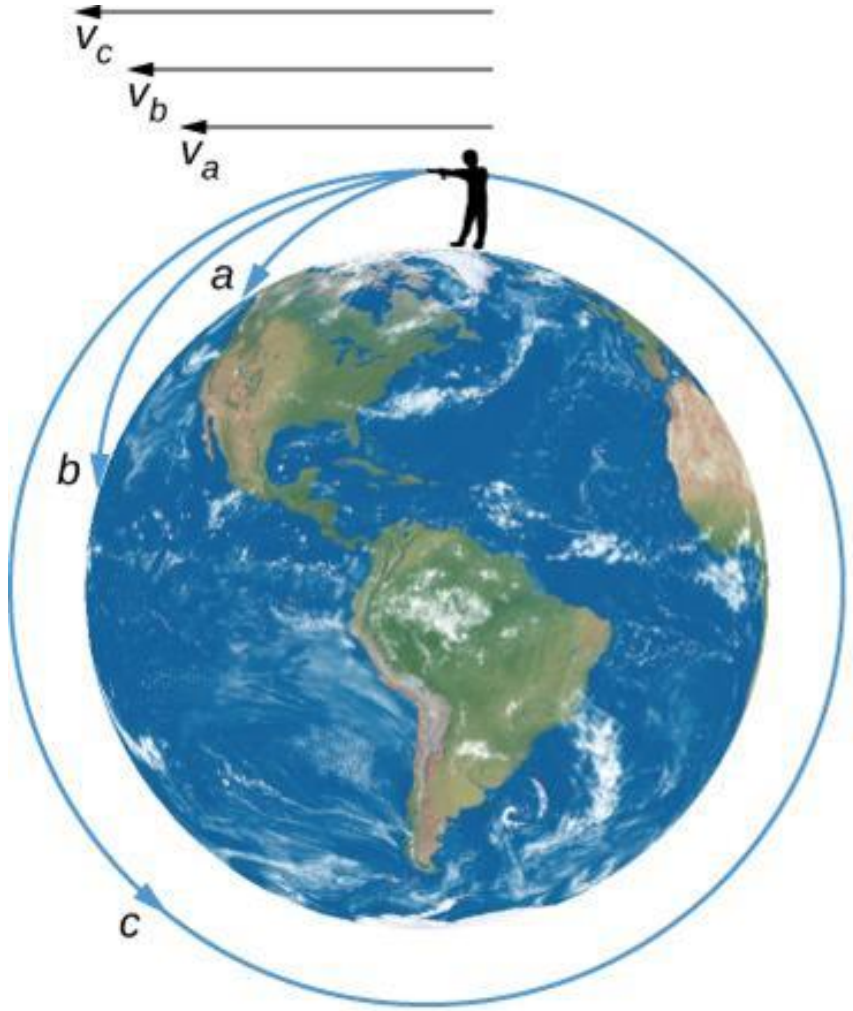
Newton's Law and Gravity

To be able to orbit something, we need the speed to be fast enough.

Too slow: object falls back to Earth

Too fast: object escapes Earth's gravity.

Just right: object is on a closed orbit. This "just right" speed for Earth is 17,500 miles per hour (8 km/s)!



Escape Velocity and Conservation of Energy

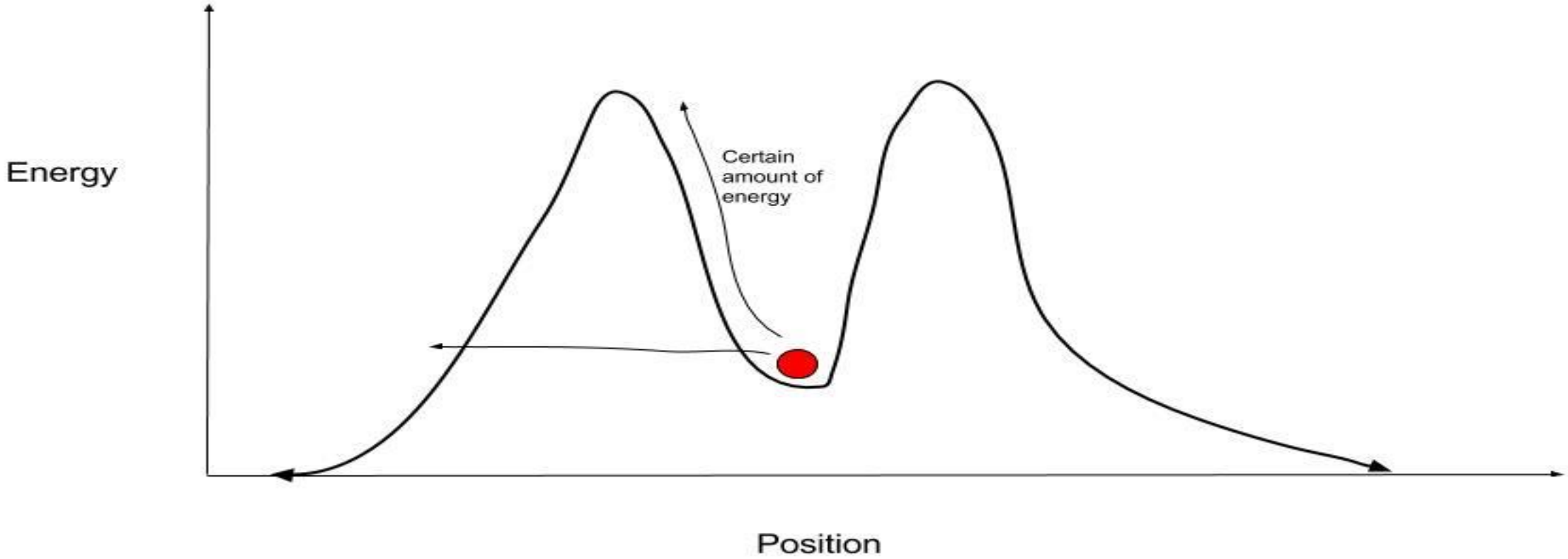
In orbital mechanics, objects also have an energy related to it's orbit. This is due to the fact that Energy is **conserved**.
There are two types of energy:

kinetic (relate to speed) $\mathrm{K} = \frac{1}{2}mv^2$

gravitational energy (related to position) $\mathrm{U} = -\frac{\mathrm{Gm}}{r}$

The energy is negative because it acts as a potential well

Potential Well



Escape Velocity

- “Escaping the potential well” means having the speed necessary to escape the gravitational influence of the central body. When this happens, the total energy in Zero.

$$E = K + U$$

$$E = \frac{Gm}{r} - \frac{1}{2}mv_{esc}^2 = 0$$

$$\frac{Gm}{r} = \frac{1}{2}mv_{esc}^2$$

$$v_{esc}^2 = \frac{2Gm}{r} \text{ -> } v_{esc} = \sqrt{\frac{2Gm}{r}}$$

Conservation of Energy

2 In Fig. 8-22, a small, initially stationary block is released on a frictionless ramp at a height of 3.0 m. Hill heights along the ramp are as shown. The hills have identical circular tops, and the block does not fly off any hill. (a) Which hill is the first the block cannot cross?

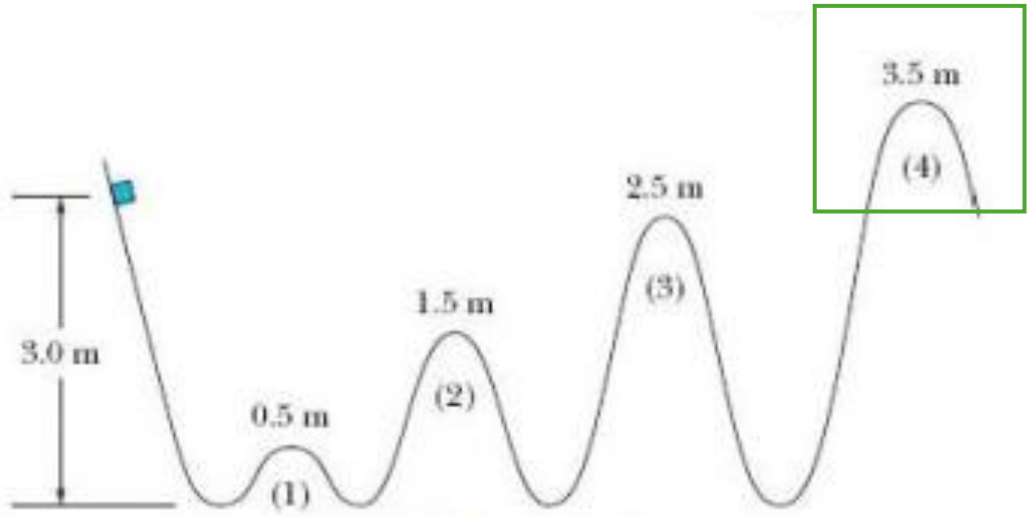


FIG. 8-22 Question 2.

Newton's Law and Gravity

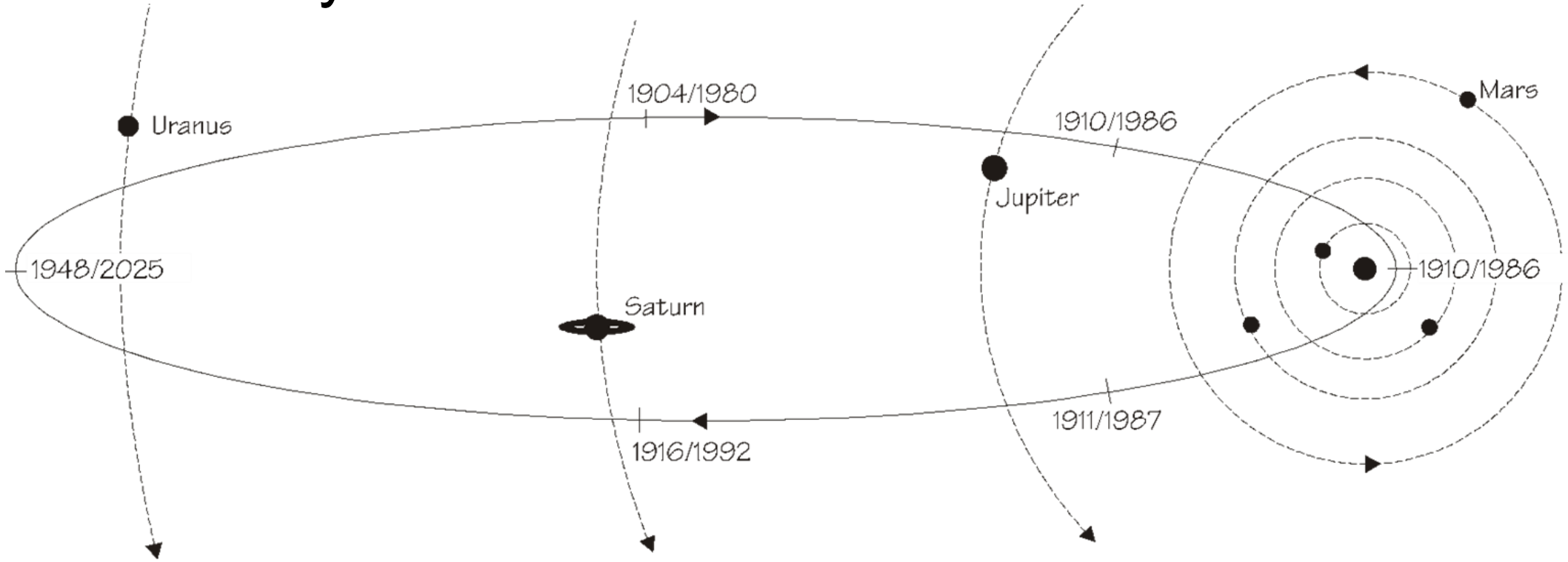
Newton's theories were published in 1688 ("Principia"). His Universal Law of Gravity combined with the Laws of Motion explain all three of Kepler's Laws of planetary motion.

These laws represent the "perfection" of the Copernican model. All planetary motions are explained with one equation, **gravity**. Geocentrism is finally wiped-out.

Can Newton's ideas be tested further?

Newton's Law and Gravity

Edmund Halley tracked part of the orbit of a comet, and predicted when it would return using Newton's laws of motion. He was exactly correct!



Newton's Law and Gravity

The planet Uranus discovered in 1781 by William Herschel. However, Uranus did not move according to predictions made with Newton's laws.

The inconsistencies could be explained by another massive object that was pulling on Uranus's orbit. Using Newton's laws of motion, a new planet was predicted to exist further from the Sun than Uranus. Neptune was found in 1845, less than 1° away from its predicted position!

Newton's laws are not only **testable and verifiable,** they are **fruitful**. The discovery of Neptune is one the great stories of the scientific method. "If I have seen farther than other men, it is because I stood upon the shoulders of giants."

Gravity on other planets

- Let’s start the Homework!