

Universal gravitation

Physics 211
Syracuse University, Physics 211 Spring 2015
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- How many of you have a calculus exam on the same day as mine?

The conical pendulum

I swing a conical pendulum of length L with angular velocity ω . What angle does the string make with the vertical?

A block on a ramp

A block of mass m_1 rests on a ramp at angle θ ; a weight of mass m_2 hangs over the side of the ramp. The coefficient of kinetic friction is μ_k .

Calculate its acceleration if it:

- ... slides down the ramp (m_2 is small)
- ... is pulled back up the ramp (m_2 is large)

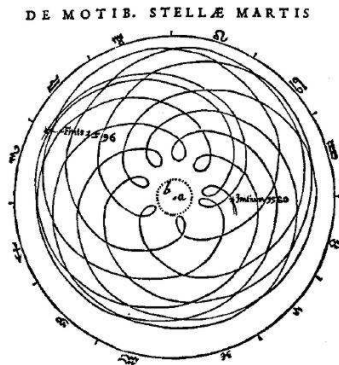
A new force: Gravity, in general

- On Earth all objects experience a gravitational force proportional to their mass:
- $F_{\text{grav}} = mg$, directed down toward the Earth
 - How does this work when you're not on Earth?
 - What determines how big g is?

A brief history of gravity and the heavens

The history here is an interesting insight into the way scientific thought has evolved: “How can we explain the sky?”

- Stars in the sky all seem to move together, but with some “wanderers”: planets
 - They appear to move in one direction, but sometimes stop and turn around



- How can we explain this?

A brief history of gravity and the heavens

- Ptolemy: Things go in circles rotating on circles, because circles are perfect, with the Earth at the center
 - “Epicycles” required to make the retrograde motion
- Copernicus: Things go in circles rotating on circles, but with the Earth at the center
 - Relative motion between Earth and planets responsible for retrograde motion
- Brahe: Fantastic measurements of motions of the planets (even more epicycles); geoheliocentrism
- Kepler: Ellipses! No epicycles needed. Laws of planetary motion.
- Galileo: Kinematics; moons of Jupiter; phases of Venus
- Newton: Universal gravitation; dynamics

Newtonian gravity

- All objects – stars, planets, apples, people – exert forces on each other
- That force is given by

$$F_g = \frac{GMm}{r^2}$$

- Both objects feel the same force, directed toward each other
- Note:

$$a_g = F_g/m = \frac{GM}{r^2}$$

- What is G ?
- → Fundamental constant of nature that tells us how strong gravity is

What are the units of G ?

(Remember, it appears in the equation $F_g = \frac{GMm}{r^2}$)

- a) m/s^2
- b) m^2/s^2
- c) $\text{N} \cdot \text{m}^2/\text{kg}^2$
- d) $\text{m}^3\text{kg}^{-1}\text{s}^{-2}$

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$$G = 6.673 \times 10^{-11} \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}$$

- This is really, really tiny

Measuring G

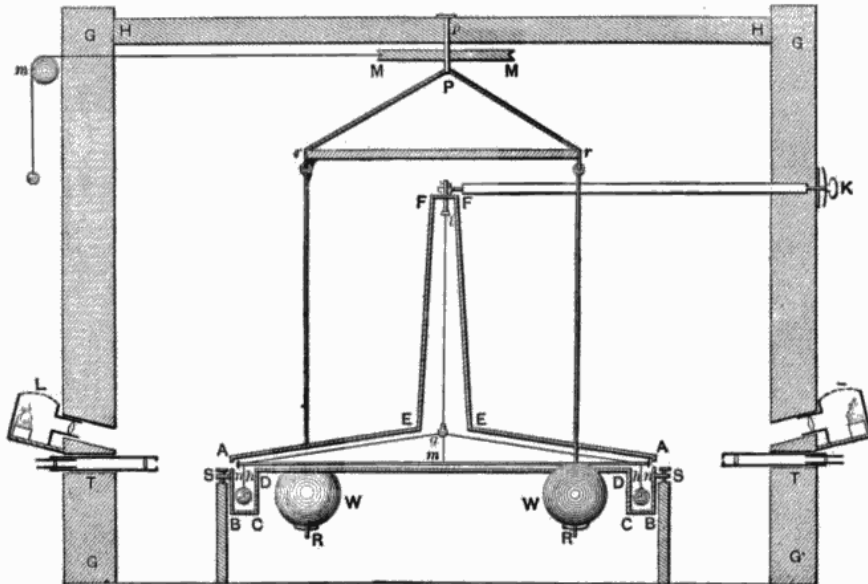


Fig. 1

Measuring G

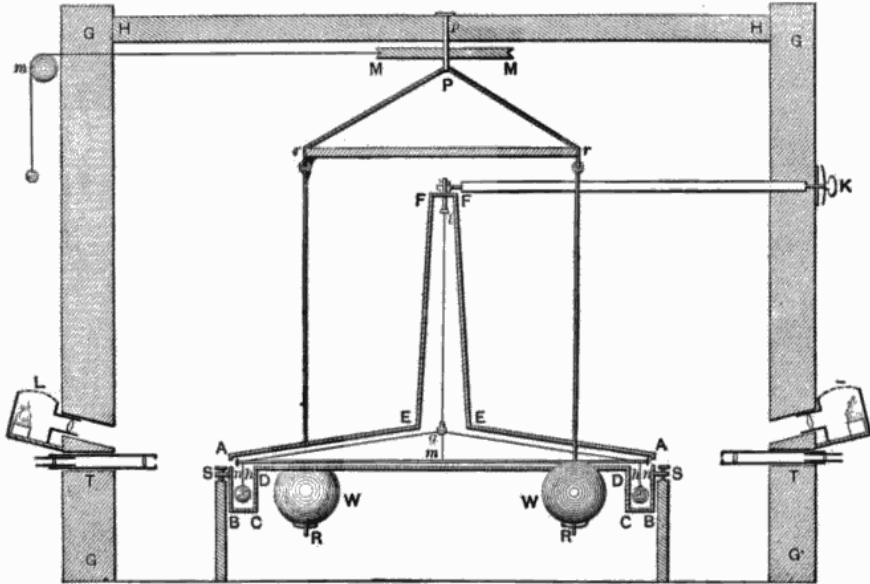
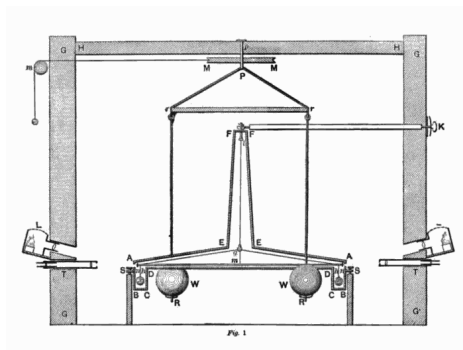


Fig. 1

What is the force between a 1kg mass and a 5kg mass that are 5cm apart?

Measuring G



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Back of the envelope math (in SI units):

$$F_g \approx \frac{(7 \times 10^{-11})(5)(1)}{5 \times 10^{-2}} = 7 \times 10^{-9} \text{ N!}$$

What is the mass of the Earth?

What is the mass of the Earth?

We have two expressions for the gravitational force:

- $F_g = mg$, where g is an empirical measurement of Earth's gravity
- $F_g = GMm/r^2$, giving the force between any two objects (not just on Earth)

$$F_g = \frac{GMm}{r^2} = mg$$

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$$M = \frac{gR^2}{G} = 5.97 \times 10^{24} \text{ kg...}$$

- Many orbits are nearly circular
- Everything you learned on Tuesday about uniform circular motion still applies
- Weighing the Earth by looking at the Moon:
 - $F_g = \frac{GM_e M_m}{r^2} = M_m \omega^2 r$
- These problems are nothing new and nothing hard; it's just a new force
- Problems involving orbits are often easier (fewer forces)