Universal gravitation

Physics 211
Syracuse University, Physics 211 Spring 2019
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Homework hints

All the problems on the homework can be solved using the same approach:

- Draw a cartoon of the situation
- Draw force diagrams for all objects (thinking carefully about the direction of forces)
  - Break "diagonal" forces into components
  - The tension is the same everywhere in a string, but you might get two "copies" of it on an object
- Write down $\sum F = ma$ in each direction for each object
- Think very carefully about what you know:
  - Are some of the accelerations zero? (Object in contact with a surface)
  - Are some of the accelerations equal, or related? (Objects linked by a string)
- Put in what you know and solve the system of equations by substitution

Homework questions? Recitation questions?

Remember, you can ask questions about the homework and recitation questions in class.

If you didn't get through all the recitation questions, that's okay.

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)

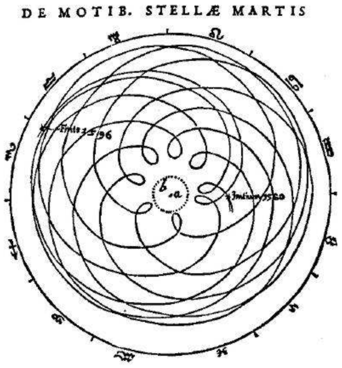
A new force: Gravity, in general

- 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?
- $\rightarrow$ 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) $\mathrm{m/s^2}$
- b) $\mathrm{m^2/s^2}$
- c) $\mathrm{N \cdot m^2/kg^2}$
- d) $\mathrm{m^3 kg^{-1} s^{-2}}$

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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

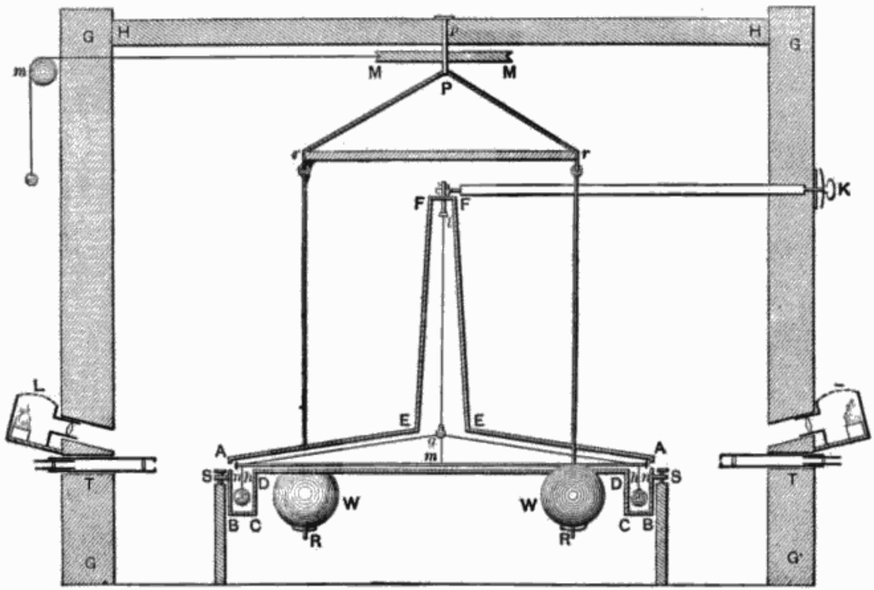


Fig. 1

Measuring G

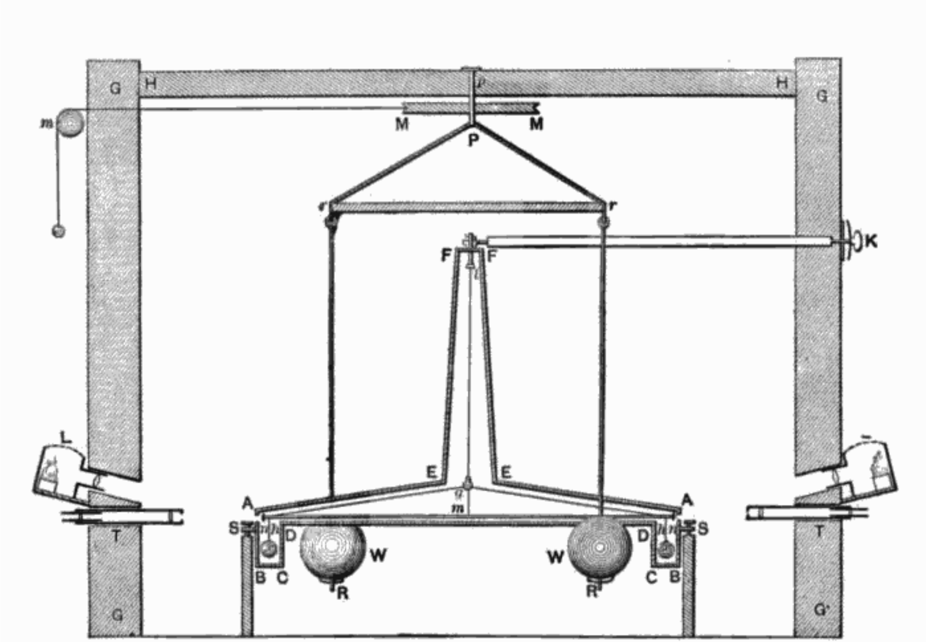
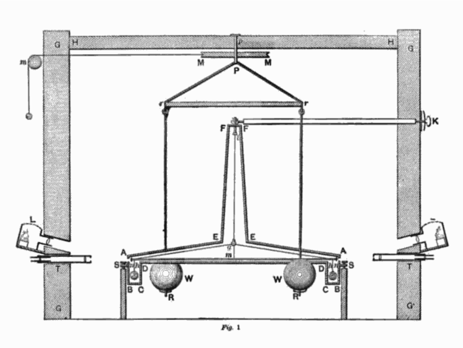


Fig. 1

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):

$$F_g \approx \frac{(7\times10^{-11})(5)(1)}{5\times10^{-2}} = 7\times10^{-9}\text{ N!}$$

Measuring the mass of the Earth

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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

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$M = \frac{gR^2}{G} = 5.97 \times 10^{24}$ 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:
  - $F_g = \frac{GM_eM_m}{r^2} = M_m\omega^2 r$
- These problems are nothing new and nothing hard; it's just a new force
- Problems involving orbits are often easier (fewer forces)

What is the mass of the Sun?