

# Universal gravitation

Physics 211  
Syracuse University, Physics 211 Spring 2022  
Walter Freeman

March 3, 2022

Help hours in the few days: (more to be added next week)

- Today, 9:45-10:30ish and 3:00-5:00 (Walter + coaches)
- Friday, 4-6 PM, room 204 (Brendan / EducationalPorpoises)
  - He is holding a workshop for people who want help learning how to “decode” physical situations and “set up” problems
- Sunday, 2:30-4:30 PM, Physics Clinic or Stolkin Auditorium – a workshop to help people prepare for Exam 2

## A block on a ramp

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

Calculate its acceleration if it:

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

# An exam question from last year: a Formula 1 car

# The “circular pendulum”: Otto on a string

# Homework questions?

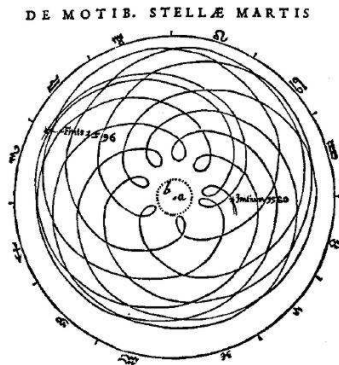
## A new force: Gravity, in general

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

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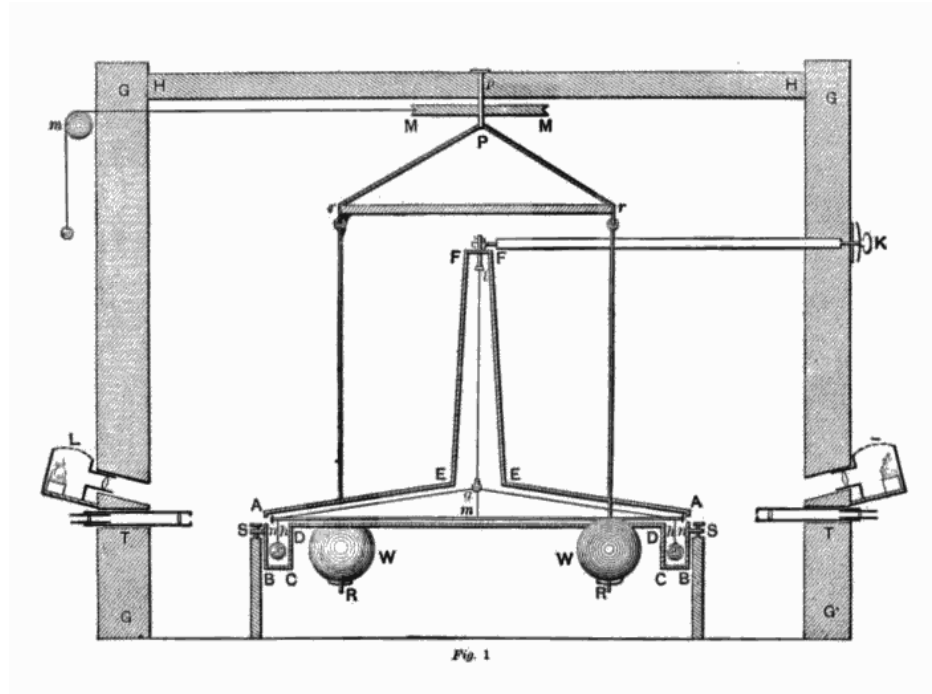
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$$G = 6.673 \times 10^{-11} \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}$$

- This is really, really tiny

# Measuring $G$



## Measuring $G$

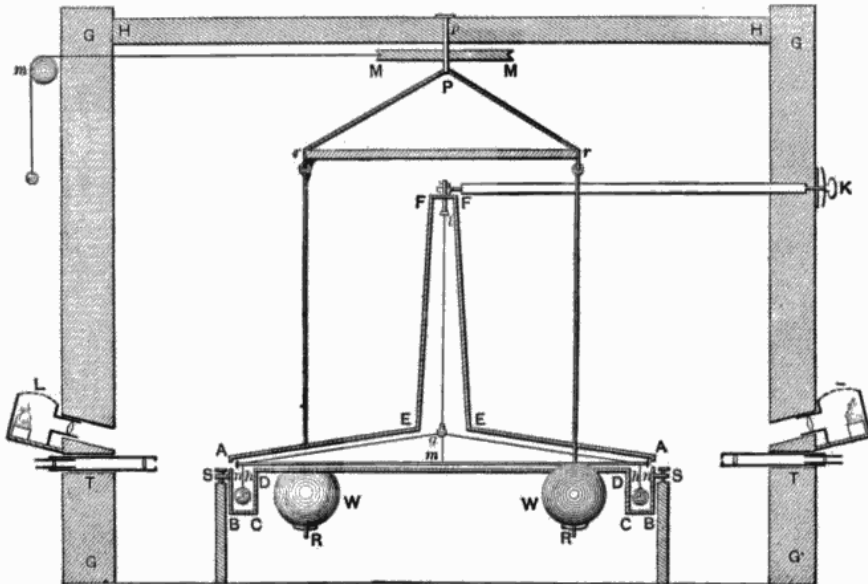
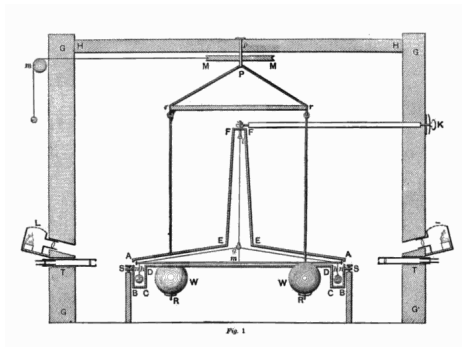


Fig. 1

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

# Measuring $G$



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

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)

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

# Measuring the mass of the Earth

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

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

- 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)