Week 5

Forces and Equilibrium

Topics for this week

1. Chaos, Atoms, Nature
2. Equilibrium systems

By the end of this week

1. Question the nature of reality
1. Be able to decompose forces into arbitrary components

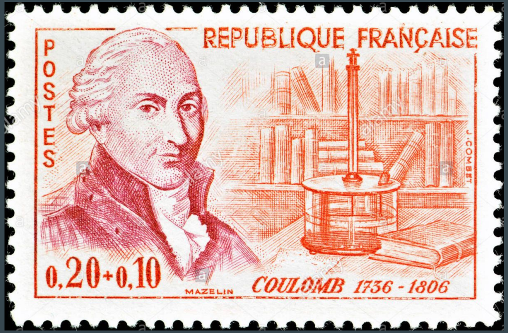
The Electric Force law

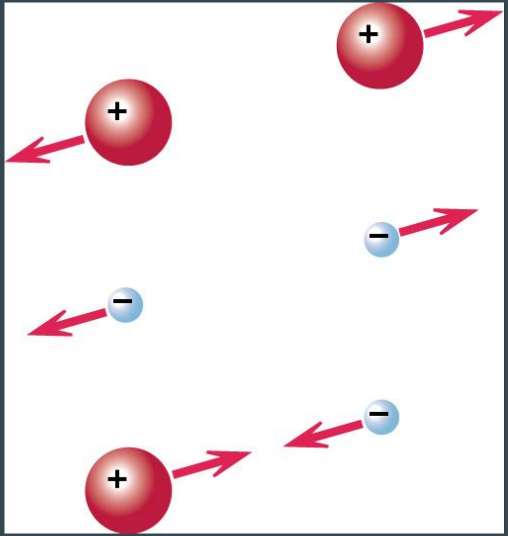
- Coulomb's Law was discovered in the 1780's by Charles-Augustin de Coulomb

$$\vec{F}_{q_1} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}|^2}\hat{r}$$

  - Obeys Newton's 3rd Law (Reciprocity)
  - The vector "r" points from "q_2" to "q_1"
  - Like the gravitational force but with a different constant

$$\frac{1}{4\pi\epsilon_0} = 9\times 10^9\,\frac{N\cdot m^2}{C^2}$$



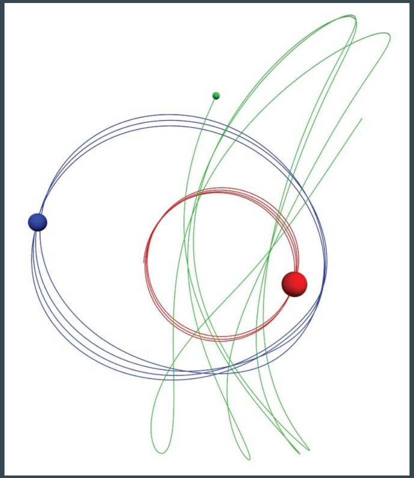


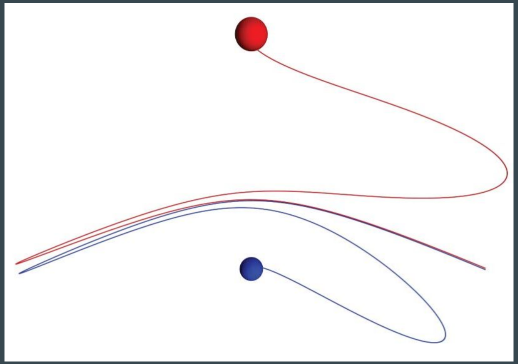
Newton or Einstein?

- Why do we hold Newton and Einstein in such high regard?
- The Newtonian Synthesis: quantify interactions in terms of a concept called force, quantify the change in motions in terms of a concept called momentum, the change in momentum equals force times Δt
  - Why does the universe work this way
- Einstein's General Theory of Relativity: massive bodies warp space and time, relativistic equations predict objects move in this altered space and time
  - Tells us things about the universe Newton missed
  - Einstein's equations are very difficult to work with and the Newtonian Synthesis works very well in most cases

Limits on predictability

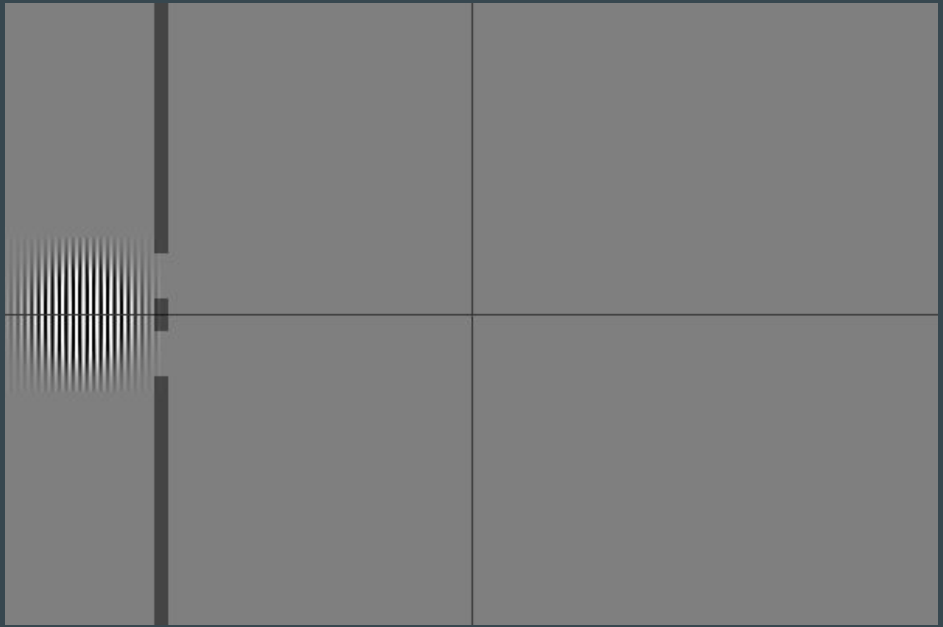
- If we know the net force and the initial position & momentum of an object can we predict the future?
  - Is the universe just a giant clock? What about free will?
- It turns out that there are many practical and theoretical limitations
  - How can we account for ALL of the interaction?
  - How can we measure the initial conditions exactly
- Even for less complex systems there are complications
  - The three body problem or “why can't we just use calculus?”
  - Some system display sensitivity to initial conditions
  - http://www.glowscript.org/#/user/ed/folder/Public/program/DP





Quantum Weirdness

- Quantum Mechanics (1920): A mathematical description of nature for predicting the behaviors of microscopic particles
  - On the very small scale, there exist a dual particle-like and wave-like behavior needed to describe interactions of energy and matter
- On the scale of the atom the universe is not deterministic!
  - We can't predict exactly what will happen only the probability of something happening



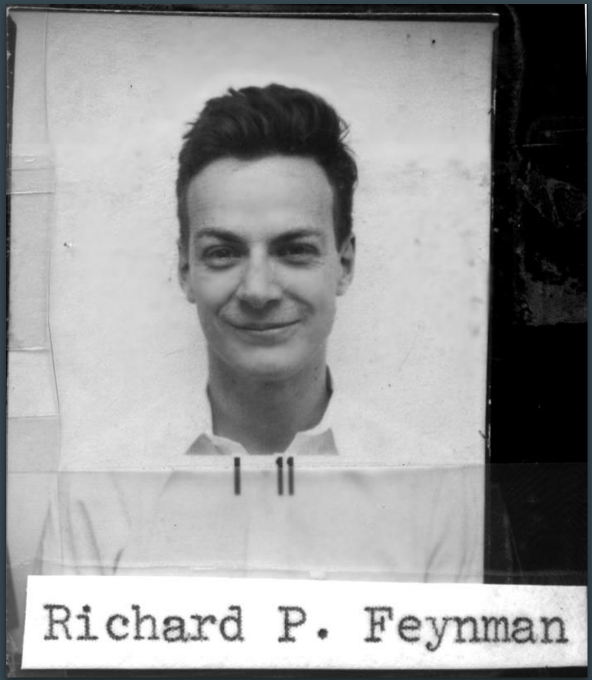
Contact Interactions

The Atomic Hypothesis

- If all scientific knowledge were to be destroyed, what one sentence should be passed on to the next generation of creatures?

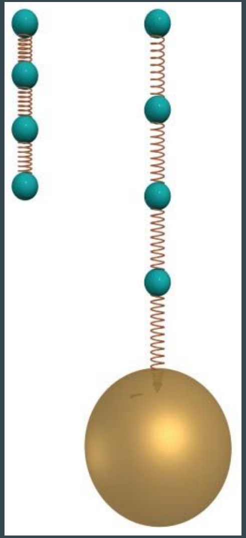
- “I believe it is the atomic hypothesis... that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied.”

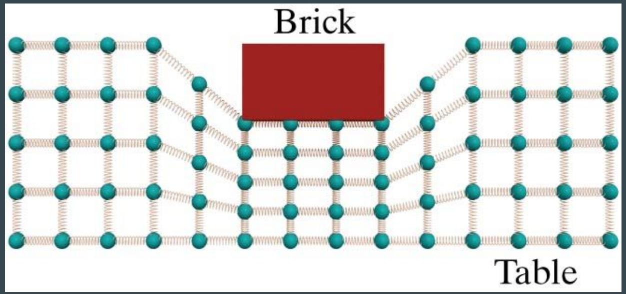
  — Richard Feynman, American physicist, Nobel Laureate in Physics (1918-1988)



Contact Forces

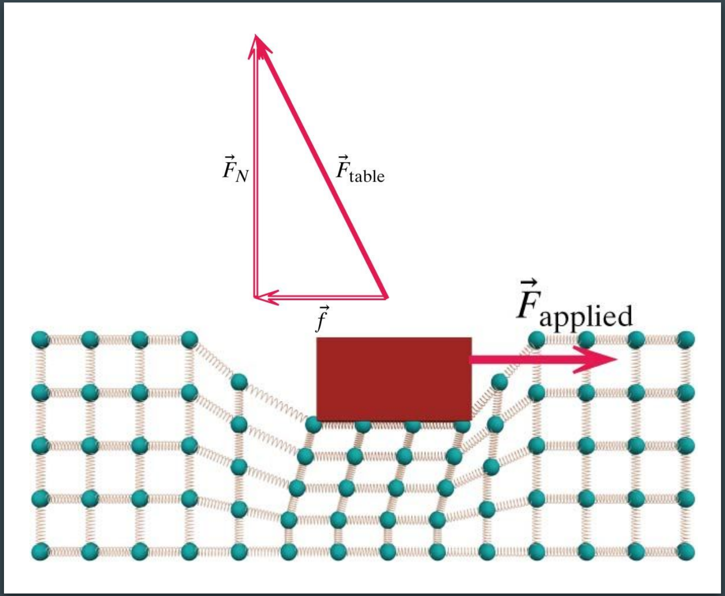
- How does a point of contact exert a variable force on the system?
  - Tension forces
    - The distance between the atoms increases resulting in a force up
  - Compression forces
    - The distance between the atoms decreases resulting in a force up
- What assumptions have we made here?
  - Massless springs/atoms
  - Springs can stretch or compress indefinitely





Compression revisited

- Two moving solids in contact feel a friction forces resisting this movement
  - This is directly related to the compression force
  - If we apply a force to a brick laying on a table, the brick will run into an uncompressed part of the table
  - This force is parallel to the table and called the frictional force
  - All of this compressing and decompressing of the bonds imparts energy into the table
    - It heats up!
- We call friction a “dissipative” process
  - We can’t reverse friction by changing direction



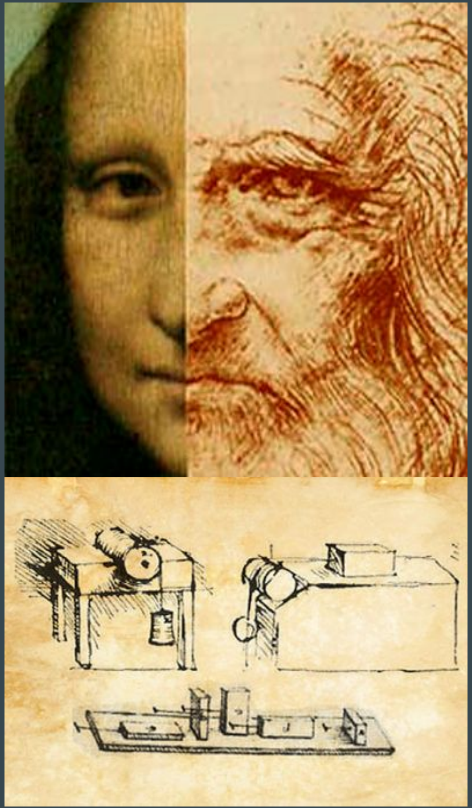
A model for friction

- Leonardo da Vinci (1452) was the first person to qualitatively study the problem of friction
  - He focused on all kinds of friction and drew a distinction between sliding, static and rolling friction

$$|\vec{f}_{sliding}| = \mu_k |\vec{F}_N|$$

$$|\vec{f}_{static}| \leq \mu_s |\vec{F}_N|$$

    - "μ" is the coefficient of friction and will have a different value for static/kinetic
    - "F_N" is the component of the contact force perpendicular to the surface



Static Equilibrium

- If the change in momentum is zero than the net force must also be zero
  - You have already solved some simple statics problems
    - The tension in hanging ball
  - More complex examples involve several forces acting on an object
  - If you are an engineer you may take an entire class on this subject

$$\frac{d\vec{p}}{dt} = 0 = \vec{F}_{net}$$

Example: Tension in equilibrium

A climber of mass "m" hangs motionless from two cables. The angle that each cable makes with the x and y axis is known. Determine the tension in each cable.

Example: Solution

- The climber is in equilibrium so the forces must sum to zero

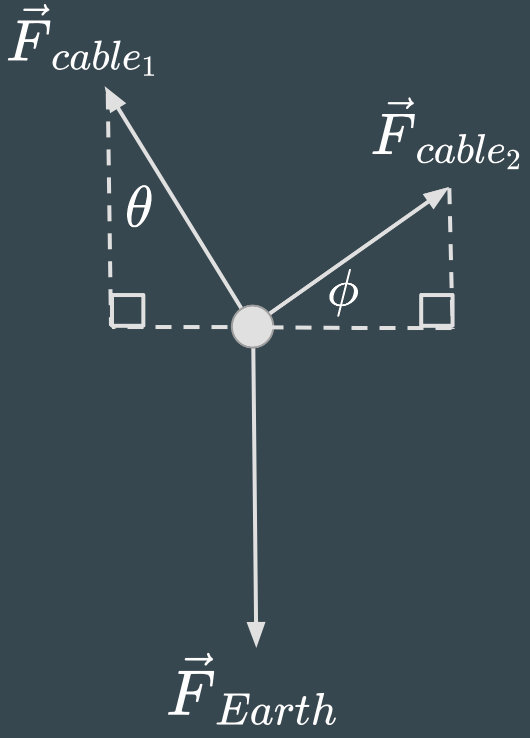
$$\frac{d\vec{p}}{dt} = 0$$

$$\vec{F}_{net} = \vec{F}_{Earth} + \vec{F}_{cable_1} + \vec{F}_{cable_2} = 0$$

- Decouple the x and y components

$$0 - |\vec{F}_{cable_1}|\sin\theta + |\vec{F}_{cable_2}|\cos\phi = 0$$

$$-mg + |\vec{F}_{cable_1}|\cos\theta + |\vec{F}_{cable_2}|\sin\phi = 0$$



Example: Solution cont.

- Solve for the tensions

$$|\vec{F}_{cable_1}| = |\vec{F}_{cable_2}|\frac{\cos\phi}{\sin\theta}$$

$$|\vec{F}_{cable_2}|\frac{\cos\phi\cos\theta}{\sin\theta} + |\vec{F}_{cable_2}|\sin\phi = mg$$

$$|\vec{F}_{cable_2}| = \frac{mg\sin\theta}{\cos\phi\cos\theta + \sin\phi\sin\theta}$$

$$|\vec{F}_{cable_2}| = \frac{mg\sin\theta}{\cos(\phi - \theta)}$$