Lecture 5: Forces

Readings: Section 4-7, Table 29-1

Key Ideas

Four Fundamental Forces
- Strong Nuclear Force
- Weak nuclear force
- Gravitational force
  - Inverse square law
- Electromagnetic force

Comparison of the Forces
Principle of Conservation

The Four Fundamental Forces

Strong & Weak Nuclear Forces
- Bind protons to neutrons inside nuclei
- Mediate nuclear reactions & radioactivity

Electromagnetic Force
- Binds electrons to nuclei and atoms to atoms
- Mediates chemical reactions

Gravitational Force
- Binds massive objects together on large scales
- Mediates orbital motions
- Long-range attractive force
- Weakest force in nature
- Obeys an Inverse Square Law

The force of gravity between the masses M_1 and M_2 separated by a distance d is

$$F = \frac{GM_1M_2}{d^2}$$

G is the gravitational constant

The Gravitational Force is inversely proportional to the *square* of the distance.

The Gravitational Force is proportional to the masses.

The force of gravity between any two objects depends only upon

Masses of the two objects. More massive objects exert a stronger gravitational force.

Distance between them . The force gets stronger as the two objects more closer together

Because the force of gravity (and therefore how fast objects are moving in orbit around each other) depends on the mass of the objects, we can use the inverse square law in various forms to derive the masses of astronomical objects if we can measure the distances between objects, their speeds, or their periods. Examples of this include

Kepler's Third Law (Box 4.4 in your book)

$$P^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

P=Period of the orbit
a=semi-major axis of the orbit
M_1+M_2=combined masses of the bodies
Gives us a way to estimate masses

Circular Speed=speed needed to sustain a circular orbit at a given radius from a massive body:

$$v_c = \sqrt{\frac{GM}{R}}$$

Circular Speed depends on:

Mass of the larger parent body (M)

Radius of the orbit (R)=distance from the center of the mass M.

Provides a way to measure masses using orbital speed instead of orbital period.

Escape Speed=minimum speed needed to escape from a gravitating body:

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

Earth's Surface: V_{esc}=11.2 km/sec
Sun's Surface: V_{esc}=615 km/sec

Gravitational Binding Energy

Amount of energy needed to disrupt an object held together by gravity

$$U \propto \frac{GM^2}{R}$$

M=Mass
R=Radius

Earth: $U_G = 2\times10^{32}$ Joules (total energy output of the Sun for ~ 12 days)

Implications:
Objects of same Radius but different Mass, the more massive object will have:
- Faster orbital & escape speeds
- Greater binding energy ("more tightly bound")

Objects of same Mass but different Radii, the larger object will have:
- Slower orbital and escape velocities
- Less binding energy ("less tightly bound")

Electromagnetism

The force between two charged particles is

$$F = \frac{Cq_1q_2}{d^2}$$

C=Coulomb constant
q_1=charge of the 1st particle
q_2=charge of the 2nd particle
d =distance between the charges

Opposite charges *attract*.
Like charges *repel*.

Electromagnetism vs. Gravity

Very similar form in the equations. Both are inverse square laws. Both the electromagnetic and gravitational forces have infinite range. But charges can be either positive or negative, while masses always attract.

Comparing the Forces

Force	Relative Strength	Range
Strong	1	10^{-15} m
Electromagnetic	1/137	Infinite
Weak	10^{-4}	10^{-16} m
Gravity	6×10^{-39}	Infinite

So why do we spend so much time talking about gravity?
Because it is the most important force over large distances and large masses. This is because the strong and weak forces are only felt over tiny ($<10^{-15}$ meter) distances, and therefore are only important when we talk about nuclear reactions. The electric force is not always attractive, the way that gravity is. Like charges repel, opposite charges attract. Therefore on the scales of macroscopic objects (dust, humans, rocks, fleas, etc.) the net electric force is zero, as the attractions and repulsions balance each other out.

Gravity: The Universal Glue

Gravity is the force that rules in the domain of astrophysics:

- Holds planets and stars together
- Controls orbits of moons around planets
- Controls orbits of planets around stars
- Binds stars into galaxies
- Binds galaxies into groups and clusters
- Binds galaxy cluster into superclusters
- Binds the Universe together

Energy and Gravity

Two kinds of energy

potential energy = energy of position
kinetic energy = energy of motion

TOTAL energy is the same="**conserved**"

Bottom line:

There is energy in position

Objects falling under the force of gravity gain kinetic energy as they get closer to the center.

Example: A Rollercoaster

Kinetic energy can be translated into other forms of energy –

it can heat gas (bulk motion turns into random motion)

it can excite electrons (by collisions)

hot gas gives off light (either emission or continuous spectra)

Measure the potential energy the gas used to have by measuring the energy radiated by the gas.

Conservation Laws

Example: Conservation of Momentum. Momentum must be the same before and after the collision of two billiard balls.

The Power of Conservation Laws: The Discovery of the Neutrino

When scientists began to measure the momentum of the particles after radioactive decay, momentum and energy did not seem to be conserved. Pauli in 1930 suggested the presence of another particle, the neutrino, that had not been detected yet. In 1956, it was detected. It has a tiny mass (<1/200,000x the electron mass), no charge and only interacts through gravity and the weak force. Very difficult to detect.

Things that are conserved

Energy (actually Mass+Energy)

Momentum

Angular Momentum

Charge

This is a very powerful statement about the way that the Universe works.