Test results

Last day to drop without a grade is Feb 29

Grades posted in cabinet and online

If you are not properly registered then come see me for your grade

Clicker Question:

In which direction would the Earth move if the Sun’s gravitational force were suddenly removed from it?:

A: in a straight line toward the Sun
B: it would continue to move in a circular orbit
C: in a straight line directly away from the Sun.
D: in a straight line perpendicular to the direction of the Sun.

Clicker Question:

There are 1000 mm in one meter. This means that a distance of 5 mm can be written as:

A: 5 x 10\(^3\) m
B: 5 x 10\(^{-3}\) m
C: 2 x 10\(^4\) m
D: 5 x 10\(^{-2}\) m

Clicker Question:

The speed of light is 3 x 10\(^8\) m/s. What is the wavelength of the radiation produced by your favorite FM radio station (at around 100 MHz where 1 MHz = 10\(^6\) Hz):

A: 0.3 meters
B: 1 meter
C: 3 meters
D: 30 meters

The Solar System

Ingredients:

- The Sun
- Planets
- Moons and Rings
- Comets
- Asteroids (size > 100 m)
- Meteoroids (size < 100 m)
- Kuiper Belt
- A lot of nearly empty space

Solar System Perspective
**Orbits of Planets**

- All orbits in the same direction.
- Most orbits in the same plane.
- Elliptical orbits, but low eccentricity for most, so nearly circular.

**Exceptions:**
- Mercury
- Pluto

<table>
<thead>
<tr>
<th>Planet</th>
<th>Orbital Tilt</th>
<th>Eccentricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>7°</td>
<td>0.21</td>
</tr>
<tr>
<td>Pluto</td>
<td>17.2°</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Sun, Planets, our Moon and Pluto to scale (mostly)**

**DEMO: Bag of Planets**

Mistakes:
- Jupiter should have rings
- Pluto should be smaller than Moon

**Two Kinds of “Classical” Planets**

<table>
<thead>
<tr>
<th>Type</th>
<th>Examples</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Terrestrial&quot;</td>
<td>Mercury, Venus, Earth, Mars</td>
<td>Close to the Sun, Small, Mostly Rocky, High Density (3.3 - 5.3 g/cm³), Slow Rotation (1 - 243 days), Few Moons, No Rings, Main Elements Fe, Si, C, O, N</td>
</tr>
<tr>
<td>&quot;Jovian&quot;</td>
<td>Jupiter, Saturn, Uranus, Neptune</td>
<td>Far from the Sun, Large, Mostly Gaseous, Low Density (0.7 - 1.6 g/cm³), Fast Rotation (0.41 - 0.72 days), Many Moons, Rings, Main Elements H, He</td>
</tr>
</tbody>
</table>

**Dwarf Planets compared to Terrestrial Planets**

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<th>Type</th>
<th>Examples</th>
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</tr>
<tr>
<td>Dwarf Planets</td>
<td>Pluto, Eris, many others</td>
<td>Far from the Sun, Very small, Rock and Ice, Moderate Density (2 - 3 g/cm³), Rotation? No Moons, No Rings, Main Elements Fe, Si, C, O, N, And an icy surface</td>
</tr>
</tbody>
</table>
Dwarf planets continued

Sequence of discovery images

How did the Solar System Form?

We weren't there. We need a good theory. We can try to check it against other forming solar systems. What must it explain?

- Solar system is very flat.
- Almost all moons and planets (and Sun) rotate and revolve in the same direction.
- Planets are isolated in space.
- Terrestrial - Jovian planet distinction.
- Leftover junk (comets and asteroids).

Not the details and oddities – such as Venus’ and Uranus’ retrograde spin.

Early Ideas

René Descartes (1596 -1650) nebular theory:

Solar system formed out of a "whirlpool" in a "universal fluid". Planets formed out of eddies in the fluid.
Sun formed at center.
Planets in cooler regions.
Cloud called "Solar Nebula".

This is pre-Newton and modern science. But basic idea correct, and the theory evolved as science advanced, as we'll see.

A cloud of interstellar gas

The associated dust blocks starlight. Composition mostly H, He.
Too cold for optical emission but some radio spectral lines from molecules. Doppler shifts of lines indicate clouds rotate at a few km/s.

Clumps within such clouds collapse to form stars or clusters of stars. They are spinning at about 1 km/s.

Clicker Question:

Which of the following is a Terrestrial planet:
A: Jupiter
B: Saturn
C: Mercury
D: Pluto
E: Neptune
Clicker Question:

In the leading theory of solar system formation, the planets:

A: were ejected from the Sun following a close encounter with another star.
B: formed from the same flattened, swirling gas cloud that formed the sun.
C: were formed before the Sun.
D: were captured by the Sun as it traveled through the galaxy.

But why is Solar System flat?

Pierre Laplace (1749 - 1827): an important factor is "conservation of angular momentum":

When a rotating object contracts, it speeds up.

Angular momentum: mass x velocity x "size" of spinning object or orbit

Well demonstrated by ice skaters . . .

DEMO - Conservation of Angular momentum

So, as nebula contracted it rotated faster.

Could not remain spherical! Faster rotation tended to fling stuff outwards, so it could only collapse along rotation axis => it became a flattened disk, like a pizza crust.

Hubble is seeing these now!

Now to make the planets . . .

Solar Nebula:

98% of mass is gas (H, He)
2% in dust grains (Fe, C, Si . . .)

Condensation theory:

1) Dust grains act as "condensation nuclei": gas atoms stick to them => growth of first clumps of matter.
2) Accretion: Clumps collide and stick => larger clumps. Eventually, small-moon sized objects: "planetesimals".
3) Gravity-enhanced accretion: objects now have significant gravity. Mutual attraction accelerates accretion. Bigger objects grow faster => a few planet-sized objects.
initial gas and dust nebula

dust grains grow by accreting gas, colliding and sticking
continued growth of clumps of matter, producing planetesimals
planetesimals collide and stick, enhanced by their gravity
result is a few large planets

Hubble observation of disk around young star with ring structure. Unseen planet sweeping out gap?

Terrestrial - Jovian Distinction

Inner parts of disk hotter (due to forming Sun): mostly gas. Accretion of gas atoms onto dust grains relatively inefficient.

Outer parts cooler: ices form (but still much gas), also ice "mantles" on dust grains => much more solid material for accretion => larger planetesimals => more gravity => even more material.

Jovian solid cores ~ 10-15 M$_{\text{Earth}}$. Strong gravity => swept up and retained large gas envelopes.

Composition of Terrestrial planets reflects that of initial dust - it is not representative of Solar System, or Milky Way, or Universe.

Asteroid Belt

Perhaps a planet was going to form there. But Jupiter's strong gravity disrupted the planetesimals' orbits, ejecting them out of Solar System. The Belt is the few left behind.

And Finally...

Remaining gas swept out by Solar Wind.

Dinosaur Killer Impact 65 million years ago

High levels of iridium in Raton Pass (I25)

The Fossil Record is Marked by Mass Extinction Events

<table>
<thead>
<tr>
<th>Extinction</th>
<th>Genus loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>End Ordovician</td>
<td>60%</td>
</tr>
<tr>
<td>End Devonian</td>
<td>57%</td>
</tr>
<tr>
<td>End Permian</td>
<td>82%</td>
</tr>
<tr>
<td>End Triassic</td>
<td>53%</td>
</tr>
<tr>
<td>End Cretaceous</td>
<td>47%</td>
</tr>
</tbody>
</table>

From Solé & Newman 2002
Clicker Question:

We can tell something of the composition of the planets by looking at their:

A: spectra  
B: radius  
C: mass  
D: magnetic fields

Clicker Question:

An asteroid impact like the one that killed off the dinosaurs is expected once every:

A: year  
B: hundred years  
C: thousand years  
D: hundred thousand years  
E: hundred million years

Result from computer simulation of planet growth

Shows growth of terrestrial planets. If Jupiter’s gravity not included, fifth terrestrial planet forms in Asteroid Belt. If Jupiter’s gravity included, orbits of planetesimals there are disrupted. Almost all ejected from Solar System. Simulations also suggest that a few Mars-size objects formed in Asteroid Belt. Their gravity modified orbits of other planetesimals, before they too were ejected by Jupiter’s gravity.

The Structure of the Solar System

~ 5 AU  ~ 45 AU