AST 301
Introduction to Astronomy

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AST 301 (Lacy), course website

Rearranged schedule for next few weeks

Today: finish Ch 8, start atmospheres

Next week: atmospheres, 2nd test

Reading:

10/4   Ch 8 (and skim Ch 12)

10/11 Ch 10

10/18 Ch 13 (back on schedule)

Topics from this week

- How terrestrial planet surface features are formed
- Mass, volume, and density: a clue to a planet's composition
- Asteroids and comets: description and origin
- What must a theory of planetary origin explain?
- Nebular theory of planetary origin
  - Gravitational contraction
  - Rotational flattening
  - Accretion to form planetesimals
  - Collisions of planetesimals to form planets
- Formation of giant planets
  - Importance of frost line
  - Core accretion vs. gravitational instability
- Age of the solar system: how it is determined

ABCD questions

Which of the following planets has the densest atmosphere?

A. Venus
B. Earth
C. Mars
D. Jupiter
E. Eris

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The part of Jupiter’s atmosphere we can see (above the clouds) is about as dense as the Earth’s. But Jupiter is gaseous almost all of the way to its center, and its average density is about the same as liquid water.

Venus has a very dense atmosphere for a terrestrial planet. It is about 1/10 as dense as liquid water.

A clue to composition

Which of the following properties of a planet gives us a good clue about its interior composition?

A. Mass

B. Volume

C. Density

D. Magnetic field

A clue to composition

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Composition: what types of atoms or molecules a planet is made of

Density = Mass / Volume

Two identical rocks glued together will have twice the mass and twice the volume of one rock.

So their density will be the same as that of one rock, and they are still made of the same stuff.

Small bodies

Asteroids and comet nuclei are two types of small bodies in the solar system. Describe two ways in which they are similar and two ways in which they differ.

Composition

Sizes

Orbits

Origin

Can they have moons?

Can you think of others?

Nebular theory

What does the word nebular mean?

Why is it an appropriate name for the theory?

Describe the stages in the nebular theory

- Molecular cloud core
- Gravitational contraction
- Rotational flattening
- Accretion to form planetesimals
- From planetesimals to planets
- Leftovers

Which explanation for the giant planets do you prefer?

1. Beyond the frost line, dust grains had icy coatings.

   So planetesimals formed from both dust and ice.

   So they started out larger than planetesimals in the inner solar system, which were made of just dust.

   They grew large enough so that their gravities were strong enough to pull in gasses.

2. There was more mass available to make planets in the outer solar system and things out there weren't orbiting as fast as near the Sun.

   So gravity could cause a clump of the nebula to pull together and form a planet made of the same stuff as the nebula was made of.

The age of the Solar System

How can we know when the solar system formed?

We think the asteroids formed during or soon after the formation of the solar system.

We can determine the ages of pieces of asteroids that hit the Earth (meteorites) by radioactive dating.

The answer we get for the oldest asteroids we’ve found is 4.5 billion years (4.5 Gyr).

How does radioactive dating work?

Potassium-Argon dating

Potassium-40 has 19 protons and 21 neutrons in its nucleus.

Occasionally, one of the protons decays into a neutron and a positron, which flies out of the nucleus.

The nucleus then has 18 protons and 22 neutrons, which makes it an argon-40 nucleus.

Some rocks contain potassium, but none would contain argon when they form, since argon is a gas.

In 1,250,000,000 years (1.25 Gyr) one half of the potassium-40 nuclei will become argon-40 nuclei, which can be trapped in the rock.

By measuring how much potassium-40 and argon-40 a rock has in it, we can determine its age.

An example

Assume a rock formed with 1,000 potassium-40 atoms in it.

Here's how many atoms it would have a various time later:

	^{40}K	^{40}Ar
0 yr	1000	0
1.25 Gyr	500	500
2.50 Gyr	250	750
3.75 Gyr	125	875

What if you found a rock with 1000 ^{40}K atoms and 3000 ^{40}Ar atoms in it?

How old do you think it is?

An example

	^{40}K	^{40}Ar
0 yr	1000	0
1.25 Gyr	500	500
2.50 Gyr	250	750
3.75 Gyr	125	875

What if you found a rock with 1000 ^{40}K atoms and 3000 ^{40}Ar atoms in it?

It must have started with 4000 40K atoms in it, or 4 times as many as in the table. If you multiply all of the numbers in the table by 4, the 2.5 Gyr line fits.

Or just ask at what time there are 3 times as many ^{40}Ar atoms as ^{40}K atoms.

Topics for next week

How can we use the concept of thermal equilibrium to calculate the temperature of the surface of a rock orbiting the Sun?

How does the result depend on the distance of the rock from the Sun?

How does the Earth’s atmosphere affect the surface temperature of the Earth?

Why do Venus and Mars have such different surface temperatures?

How are we changing the Earth’s atmosphere, and how do we think this will affect the surface temperature?

The terrestrial planets

All four terrestrial planets have interiors made mostly of partially molten metals (iron) and rocks. Mercury and Mars have about ½ the diameter of Earth and Venus.

Mercury has almost no atmosphere. Its surface temperature ranges from 100K to 700K (-300^{o}F to 800^{o}F).

Venus has about 100 times denser atmosphere than the Earth's. Its surface is a uniform 740K (880^{o}F).

Earth has an atmosphere about 1000 times less dense than liquid water. Its average surface temperature is about 290K (60^{o}F).

Mars has an atmosphere about 100 times less dense than the Earth's. It surface temperature ranges from 130K to 290K (-220^{o}F to 70^{o}F).

Why are these atmospheres and temperatures so different?

Equilibrium

A balance between opposing influences

Consider a mass hanging from a spring.

Gravity pulls it downward. The spring pulls it upward.

If gravity and the spring pull equally hard in opposite directions, the mass will not move.

It is in equilibrium.

If we increase the mass, gravity will pull harder.

As a result, the spring will stretch.

This will make the spring pull harder, until the spring force and gravity balance again. The mass will stop moving, and it will again be in equilibrium.

Equilibrium

A balance between opposing influences

Consider a can with a hole in its bottom, held under a faucet.

Is it possible for the level of water in the can to come to an equilibrium?

What are the opposing influences?

What would happen if you turned up the flow of water into the can?

Equilibrium

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Consider a can with a hole in its bottom, held under a faucet.

Is it possible for the level of water in the can to come to an equilibrium?

What are the opposing influences?

What would happen if you turned up the flow of water into the can?

The level of the water in the can would rise.

If the can was very tall, would the water level just keep on rising or would it come to a new equilibrium level?

A new equilibrium

If one influence changes, we could have a new equilibrium if that made the other influence change.

If the flow of water into the can increased, the water level would rise.

That would increase the pressure in the can causing the flow out of the can to increase too.

If the flow out rose to equal the flow in, the water level would stop rising.

We would have a new equilibrium.

A rock in space

Consider a black rock orbiting the Sun.

Energy is flowing into the rock because it is absorbing sunlight.

If there were no way for energy to flow out of the rock, what would happen?

A. it would get hotter and hotter until it vaporized

B. it would get hot but it would never vaporize

C. it would be kept cool because space is cold

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How does energy flow out of a rock in space?

A. by radiation from the rock

B. by conduction into the surrounding space

C. by reflecting sunlight

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How does energy flow out of a rock in space?

A. by (infrared) radiation from the rock

B. by conduction into the surrounding space

C. by reflecting sunlight

Flow of energy = Power

The temperature of the rock will come to an equilibrium if the flow of energy out of the rock (by radiation) balances the flow into the rock (by absorbing sunlight).

The unit used to measure energy is the Joule.

The unit used to measure the flow of energy, or power, is the Watt.

One Watt is one Joule per second.

A 100 Watt light bulb has 100 Joules of electrical energy flowing into it each second.

Less than 10 Joules of visible light come out of the light bulb each second.

The rest comes out as infrared radiation or is conducted into the air around the light bulb.

Calculating the rock's temperature

To calculate the temperature of the rock orbiting the Sun, we need to write down the formulas for the energy going into the rock and the energy going out each second.

Power going in is the flux of sunlight multiplied by the area of the side of the rock facing the Sun.

$P_{in} = F_{sunlight} \times A_{face}$

Power going out depends on the temperature of the rock and its total surface area.

$P_{out} = \sigma T^4 \times A_{surface}$

In equilibrium, $P_{out} = P_{in}$

Do the math

If $P_{out} = P_{in}$:

$$\sigma T^4 A_{surface} = F_{sunlight} A_{face}$$

$$T^4 = \frac{F_{sunlight}}{\sigma} \frac{A_{face}}{A_{surface}}$$

$$T = \sqrt[4]{\frac{F_{sunlight}}{\sigma} \frac{A_{face}}{A_{surface}}}$$

For a sphere, $A_{face} / A_{surface} = 1/4$.

The answer comes out to 279 K, or 6^o C, or 42^o F.