Monday Feb. 7

Syllabus and class notes are at: www.as.utexas.edu
go to courses, AST301 – Introduction to Astronomy – Lacy

For this week you should have read Chapters 5.1 and 6
(but we’re going to wait until Wednesday for the quiz)

If you want help on homework or anything covered in the
course, come to discussion session Thursday at 6:00
in RLM 15.216B.
Or TA or prof. office hours (see syllabus)
Topics for this week

What is a photon?  What is an electromagnetic wave?  How are the photon and wave pictures of light related?  Make a sketch of an atom, showing its parts.

How do the wave properties of electrons result in only certain electron orbits being allowed in an atom?  How does the fact that only certain electron orbits can occur result in photons of only certain wavelengths being emitted?

Describe emission and absorption line spectra and the conditions under which each occurs.

Describe black body radiation and the relations between temperature and the power emitted and the wavelengths of light emitted.

Describe the Doppler shift.
Proportions

What does it mean to say that one quantity is proportional to another?

For example, success is proportional to effort. If you double your effort you will double your success. Or success equals some number times effort.

Or area is proportional to width squared. If you triple the width you will multiply the area by 9 \((3^2)\).

For a square, \(A = w^2\), so the number equals 1.

For a circle, \(A = \pi r^2 = (\pi/4)d^2\), so the number equal \(\pi/4\).

But if we are comparing two objects we don’t need to know the number in the equation.

\[
\frac{A_1}{A_2} = \left(\frac{d_1}{d_2}\right)^2
\]
Quiz

Three of you go into Double Dave’s to buy some pizza. You all like anchovies and garlic, and you are willing to share one pizza if you get more to eat that way. You each have $5 to spend. They are selling 6-inch pizzas for $5 each and 12-inch pizzas for $15 each. Should you buy three 6-inch pizzas or one 12-inch pizza? (Assume all pizzas have the same thickness, so the area determines how much you get to eat.)

A. Three 6-inch pizzas
B. One 12-inch pizza.
Pizzas

B. Buy the 12-inch pizza.
Since area is proportional to width squared, it has 4 times the area of a 6-inch pizza, so you get 4 times as much to eat for 3 times as much money.

\[
\frac{A_{12''}}{A_{6''}} = \frac{(12/6)^2}{2^2} = 4
\]

Or if you want to keep \( \pi \) in the formula,

\[
\frac{A_{12''}}{A_{6''}} = \frac{\pi \ 6^2}{\pi \ 3^2} = \frac{36 \ \pi}{9 \ \pi} = 4
\]

But the answer is the same, so why bother?
Galileo’s contributions to science

In addition to his support of the Copernican model of the Universe, Galileo argued that science should be based on observations and experiments, not on pure thought. In his book, “Dialogues on Two New Sciences” he began the modern study of motion and materials.

Galileo’s most famous experiment was dropping two balls off of the leaning tower of Pisa. Most people thought the heavier ball would fall faster. What actually happened?

About 100 years later, Newton continued Galileo’s study of motion (and other sciences).
Newton’s theory of motion

Common experience tells us that you have to push on an object to make it move and the harder you push the faster it goes.
If you stop pushing on an object it will stop moving.

Newton realized that this is a result of a complicated situation involving friction.
In a simple situation (like an object in space or a very smooth ball rolling) the rules are different.
And the rules for simple situations can be combined to explain motion in complicated situations.

Newton also realized that his laws of motion when applied to the planets could explain Kepler’s laws.
Newton’s laws of Motion

1. If there are no forces acting on an object, if moving, it will continue to move with constant speed and in the same direction. If not moving, it will remain stationary.

2. If a force is acting on an object, the object’s acceleration (the rate of change in its speed or direction of motion) is proportional to the force acting on it and is inversely proportional to its mass.

   \[ a \propto \frac{F}{m} \]

3. If an object exerts a force on a second object, the second object necessarily exerts the same force on the first, but in the opposite direction.
Newton’s law of gravity

Gravity is an attraction between any two objects. The force of gravity is proportional to the product of the masses of the two objects and is inversely proportional to the distance between their centers.

\[ F \propto \frac{m_1 \cdot m_2}{d^2} \]

or

\[ F = G \frac{m_1 \cdot m_2}{d^2} \]
Quiz

When the Apollo astronauts were on the way to the Moon, 10 Earth radii away from the Earth (1/6 of the way to the Moon), what was the force of gravity on a 150 pound astronaut?

A. 0
B. 1.5 lb
C. 15 lb
D. 150 lb
Quiz

When the Apollo astronauts were on the way to the Moon, 10 Earth radii away from the Earth (1/6 of the way to the Moon), what was the force of gravity on a 150 pound astronaut?

A. 0
B. 1.5 lb
C. 15 lb
D. 150 lb

The force of gravity is inversely proportional to the square of the distance between two objects, so if the astronaut was 10 times as far from the center of the Earth as he was when standing on the Earth, the force of gravity on him was 100 times weaker than on Earth.
Newton’s explanation of Galileo’s experiment

If the two balls that Galileo dropped from the leaning tower had different masses, the force of gravity on them should have been different. Why did they fall at the same rate?

What if one ball had a mass of 1 kilogram and the other had a mass of 2 kg? The force of gravity on the 2 kg ball was twice the force on the 1 kg ball and Newton’s 2\textsuperscript{nd} law says that acceleration is proportional to the force on an object.

But Newton’s 2\textsuperscript{nd} law also says that acceleration is inversely proportional to the mass of the object.

Doubling the force and doubling the mass have opposite effects, resulting in the same acceleration for the two balls.
Galileo (and Einstein) just argued that all objects accelerate the same under the influence of gravity. Newton explained that by saying that the force of gravity is proportional to mass, and acceleration is proportional to force / mass.

If the force of the Earth’s gravity on a 1 kg ball is 10 Newtons, what is the force of the ball’s gravity on the Earth?

A. much less than 10 Nt.
B. 1 Nt
C. 10 Nt.
D. much more than 10 Nt.
If the force of the Earth’s gravity on a 1 kg ball is 10 Newtons, what is the force of the ball’s gravity on the Earth?

A. much less than 10 Nt.
B. 1 Nt.
C. 10 Nt. Newton’s 3rd law requires it to be the same.
D. much more than 10 Nt.

But then why doesn’t the Earth accelerate toward the ball? Or does it?
Newton’s version of Kepler’s 3rd law

Newton’s laws can be used to derive Kepler’s 3rd law.
A force is needed to cause a planet to move on a curved path. That force is the force of gravity of the Sun.
By equating the force of the Sun’s gravity to the force needed to cause a planet to follow a curved path, we can calculate the speed of the planet.
The result is: \( v = (G \frac{M_{\text{Sun}}}{a})^{1/2} \),
where \( v \) is the average speed of the planet, \( M_{\text{Sun}} \) is the mass of the Sun, and \( a \) is the average distance of the planet from the Sun.
Knowing the speed of the planet, we can calculate the time it takes to orbit the Sun.
The result is: \( P^2 \propto \frac{a^3}{M_{\text{Sun}}} \)
The Math

\[ F_{\text{on Earth}} = G \, M_{\text{Earth}} \, M_{\text{Sun}} / r^2 \]

\[ a_{\text{of Earth}} = F_{\text{on Earth}} / M_{\text{Earth}} = G \, M_{\text{Sun}} / r^2 \]

\[ a_{\text{in orbit}} = v^2 / r \]

for \( a_{\text{of Earth}} = a_{\text{in orbit}} \) we need:

\[ G \, M_{\text{Sun}} / r^2 = v^2 / r, \text{ or} \]

\[ G \, M_{\text{Sun}} = v^2 \, r, \text{ or} \]

\[ v^2 = G \, M_{\text{Sun}} / r \]

but we also know that \( v = \text{distance/time} = 2\pi r / P \), so

\[ G \, M_{\text{Sun}} = (2\pi r / P)^2 \, r = 4 \, \pi^2 \, r^3 / P^2, \text{ or} \]

\[ P^2 = (4 \, \pi^2 / G \, M_{\text{Sun}}) \, r^3, \text{ or} \]

\[ P^2 \propto r^3 \]

(and for a circle, \( r = a \), the semimajor axis)
What is light?

We need two ways of looking at light:

Light is an electromagnetic wave.

We often think of radio waves this way.
In fact they are just very long wavelength light.
(They are not sound waves.)

Light is also a shower of particles called photons.

x-rays are usually thought of as photons.
They are very short wavelength light.

For visible light we need both pictures.

It is best to think of a photon as a wave packet.

The mathematical connection between the two pictures of light is given by:

\[ E_{\text{photon}} = \frac{hc}{\lambda} \]
What is an atom?

A hydrogen atom has one proton at its center, with one electron orbiting around the proton.

The proton has a positive electrical charge.
The electron has a negative charge and is about 2000 times less massive than the proton.

Opposite charges attract, with a force law like that for gravity, so we expect the electron orbit to obey laws like Kepler’s laws.

Other atoms have additional protons in their nuclei and additional electrons orbiting around their nuclei.
The also have neutrons (electrically neutral particles with masses similar to proton masses) in their nuclei.