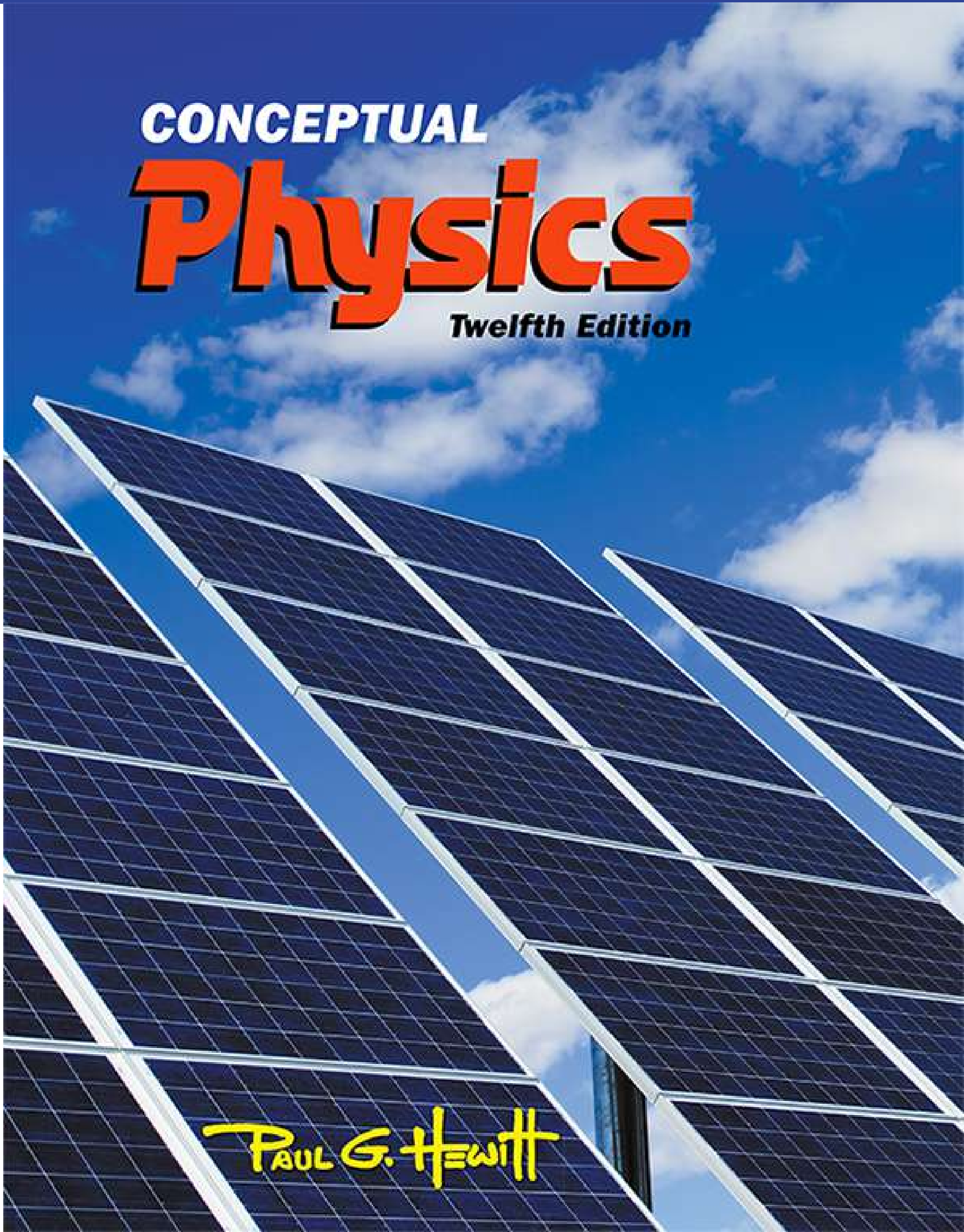
Chapter 8: Rotational Motion

Section 8.5: Angular Momentum



This lecture will help you understand:

- Why a basketball balances when spun.
- How to stand a dime on its edge.
- How to tell a raw from a cooked egg.
- Why rifles were invented.
- How a cellphone knows how it’s being held.
- Why the North Star is always changing.

Review: Linear Momentum

Linear momentum = mass x velocity

$$p = m \times v$$

Which part of this equation is the inertia? m

Which part is the "motion?" v

Is momentum a vector? yes

p = 2 kgm/s, east

What are the two ways that momentum can change?

1. its magnitude (the number plus units)
2. its direction

Angular Momentum

→The "inertia of rotation" of rotating objects is called **angular momentum.**

Angular momentum = rotational inertia x angular velocity

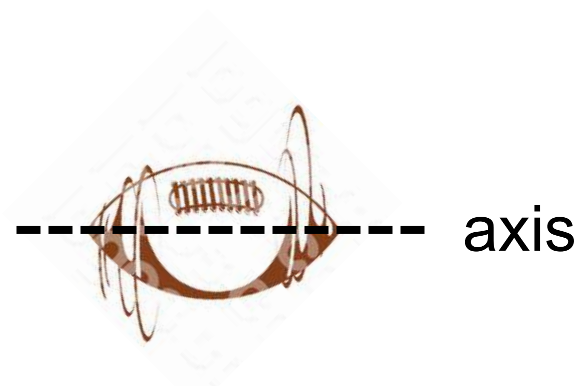
$$L = \underbrace{I}_{mr^2 \,=\, \text{mass x distance}^2} \times \underbrace{\omega}_{\text{rotations or revolutions per time (rpm)}}$$

L is a vector that points along the axis of rotation.

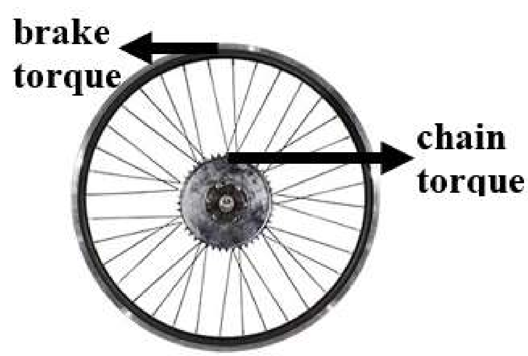
Newton's Laws for Rotating Objects:

1. If there is **no net torque** acting on an object, the object keeps rotating at the same speed in the same direction.

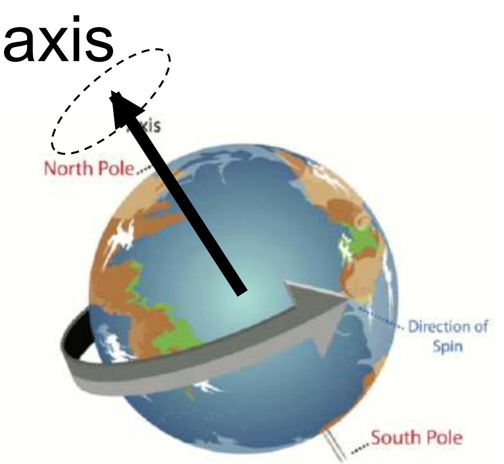
2. If there is a **net torque**, either the speed changes or the direction (axis) changes.



no net torque



net torque:
speed changes



net torque: axis
direction changes

Ex 1: Fingertip balancing

A ball is spinning on a finger. To be stable, the ball must continue to spin.

A) What will happen if the ball slows down and stops?

it falls off

B) What force from what object exerts the torque to slow the ball down?

friction between the finger and ball

Ex 2: A example worth 10 cents

What is an easy way to get a dime to "stand on edge" on a table?

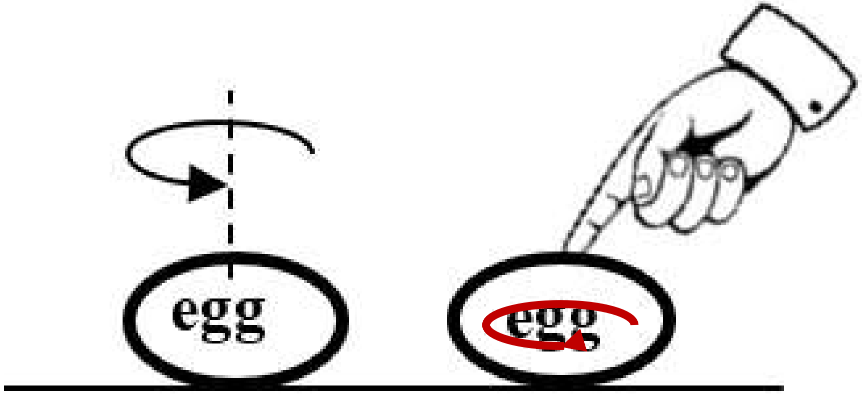
spin it

What kind of momentum are you giving it?

angular

Ex 3: Raw vs. hardboiled eggs

Two eggs are spun.
One egg is hard-boiled.
One is raw.
A finger touches each egg briefly.



A) Why does the *raw* egg keep spinning after touching it?

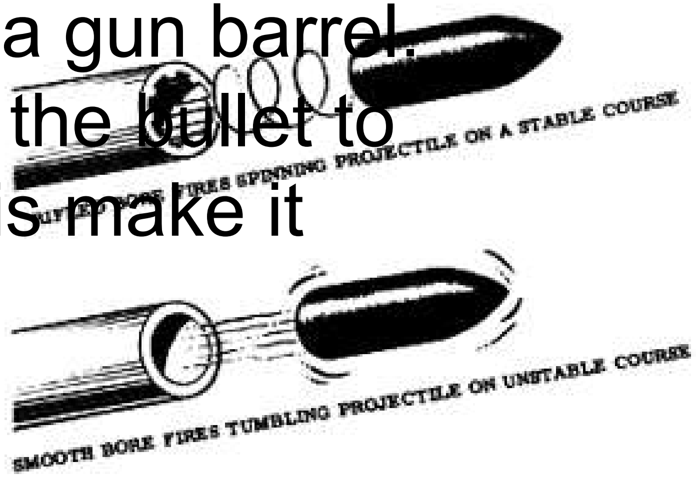
liquid inside keeps spinning

B) You spin yourself around fast, then stop. Why do you feel dizzy?

liquid inside your ear keeps spinning

Ex 4: Rifling

Rifling is a grooved pattern on a gun barrel. The grooves exert a torque on the bullet to start it spinning. Why does this make it more stable and go further?



it's spinning and it wants to keep spinning

What kind of momentum does it have?

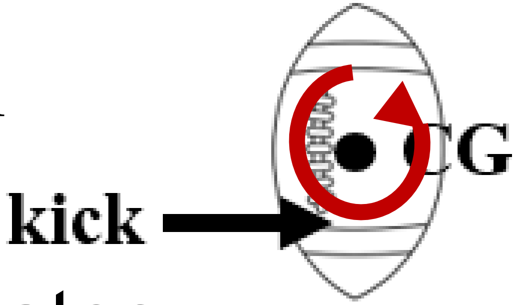
angular momentum

Ex 5: On the football field:

1. What do quarterbacks usually do to a football to make it stable?

Torque it, which makes it do what?
rotate or spin or spiral

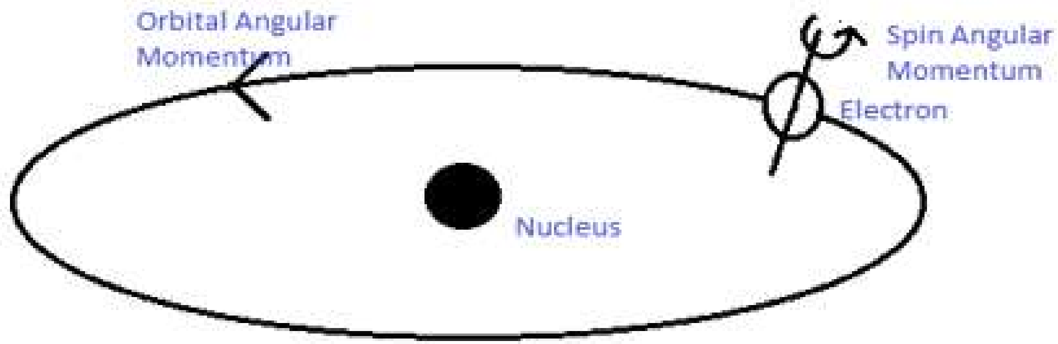
2. Why do kickers kick the football off center?



to torque it, so that it rotates

Because it has angular momentum, it will keep spinning in the same direction.

Ex. 6: Electrons



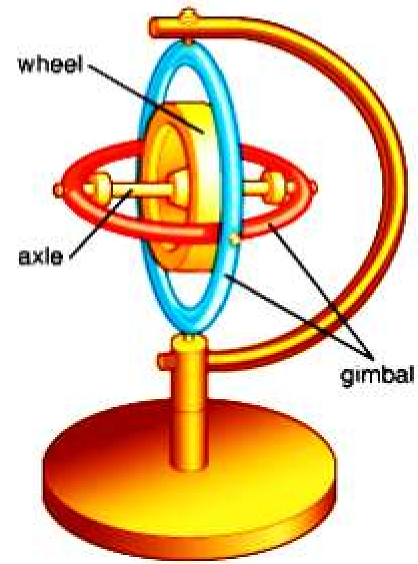
In atoms, electrons have 2 types of angular momentum: **orbital** (going around the nucleus) and **spinning** on its own axis.

Is orbiting a rotation or a revolution? revolution

Is spinning a rotation of a revolution? rotation

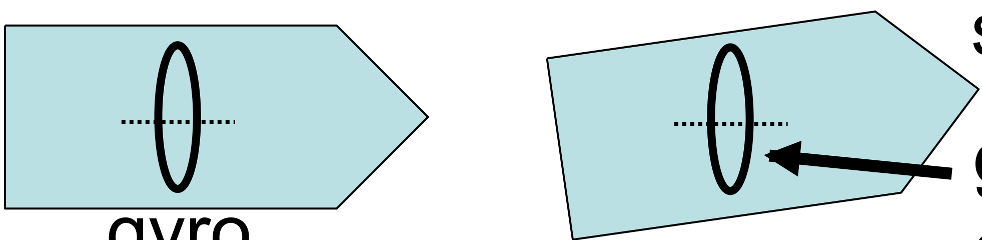
What kind of momentum does it have? angular

Ex. 6: Gyroscope



A gyroscope is a spinning wheel used in planes and ships. If it is dark or cloudy and you cannot see the horizon, it helps to keep the ship pointed in the correct direction.

ship



gyro

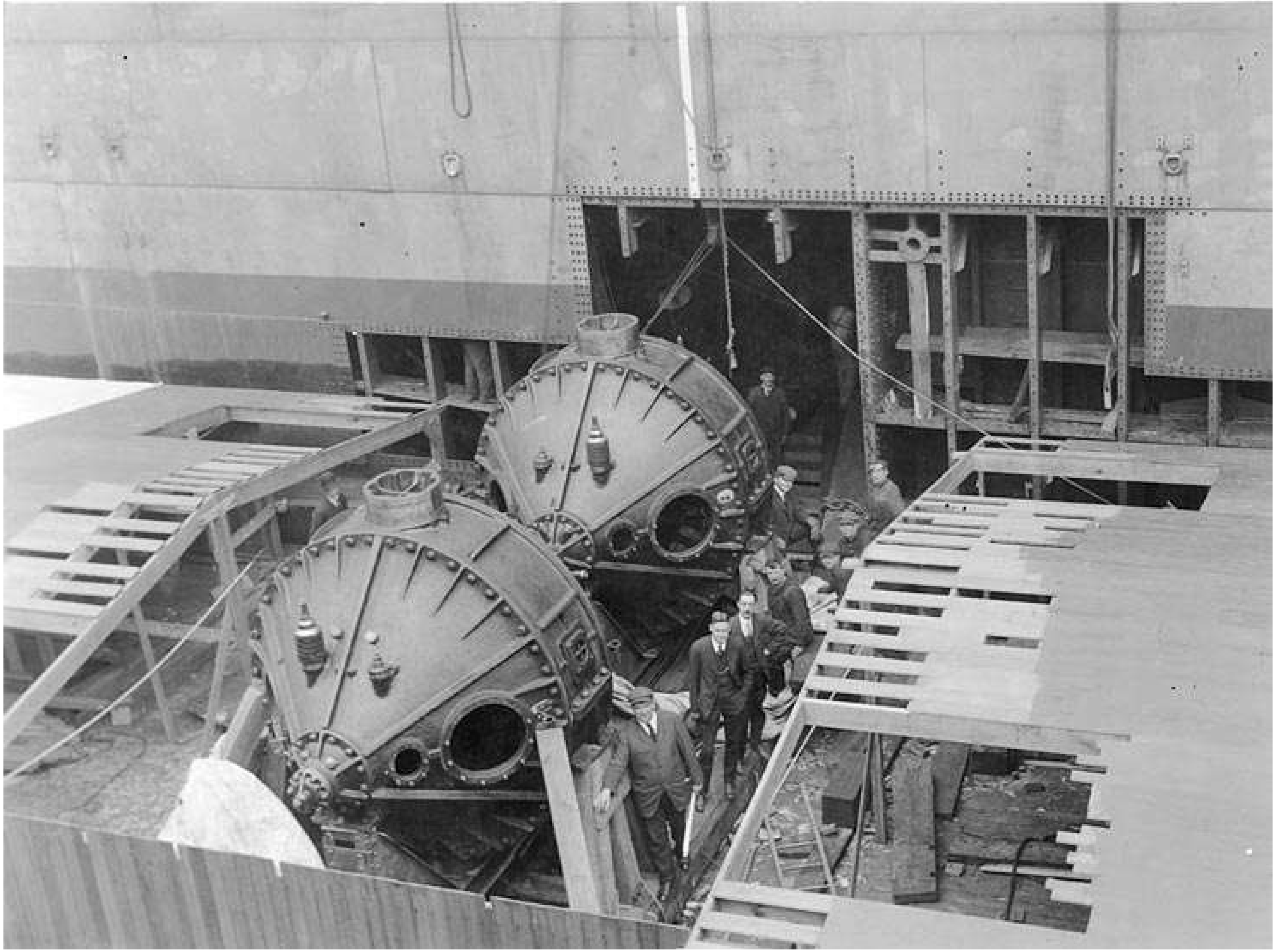
ship changes direction

gyro doesn’t b/c it has angular momentum

Nowadays gyroscopes are electronic. What other device that you have “knows” in what direction you are pointing it?

cell phones,
Wii consoles,
VR goggles,
etc

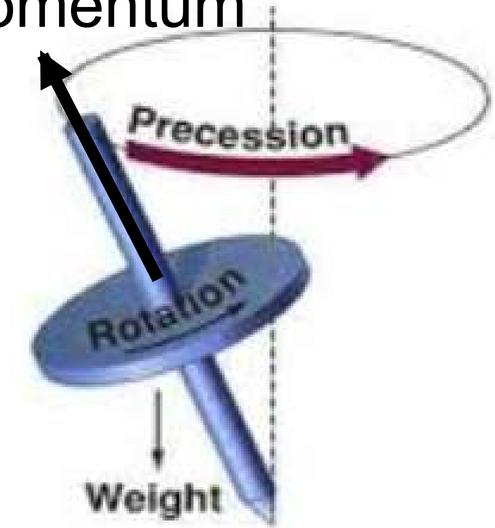
Titanic's anti-rolling gyros:



In cell phone:

Ex 7: Precession

axis = direction of angular momentum



When a top spins, there is a torque due to gravity. This torque causes the direction of the top axis to move around in a circle.

Angular momentum is a vector.

It has a magnitude and a direction (same as axis).

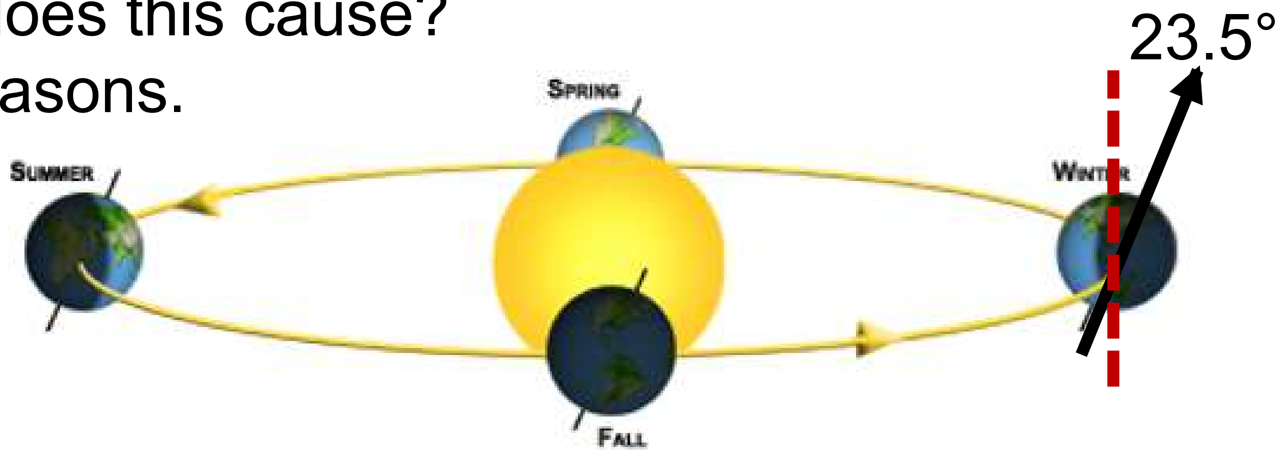
Is gravity's torque causing the *magnitude* or the *direction* of the angular momentum to change?

The direction.

This is called *precession*.

Ex 8: Earth's precession: Background

Earth rotates about its axis as it revolves around the sun.
The axis is tilted 23.5° This is called the *obliquity*.
The axis remains angled the same during 1 year.
What does this cause?
The seasons.



In which season does the axis lean towards the Sun?

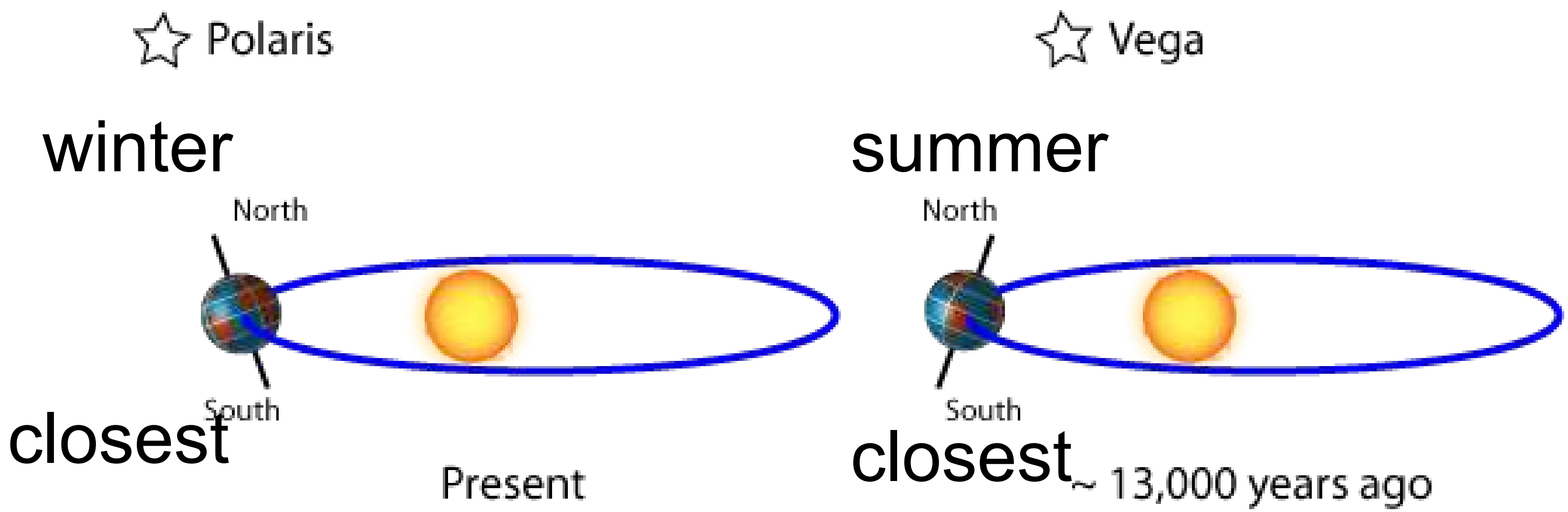
Summer.

Is Earth closest or furthest from the Sun at this time?

Further, and this makes summers milder than otherwise….

Because of the gravitational torque due to the Sun and the Moon, the Earth’s axis slowly precesses.

It takes 26,000 y for the axis to precess once!



In 13,000 years, the axis will lean towards the Sun when we are closest to the sun.

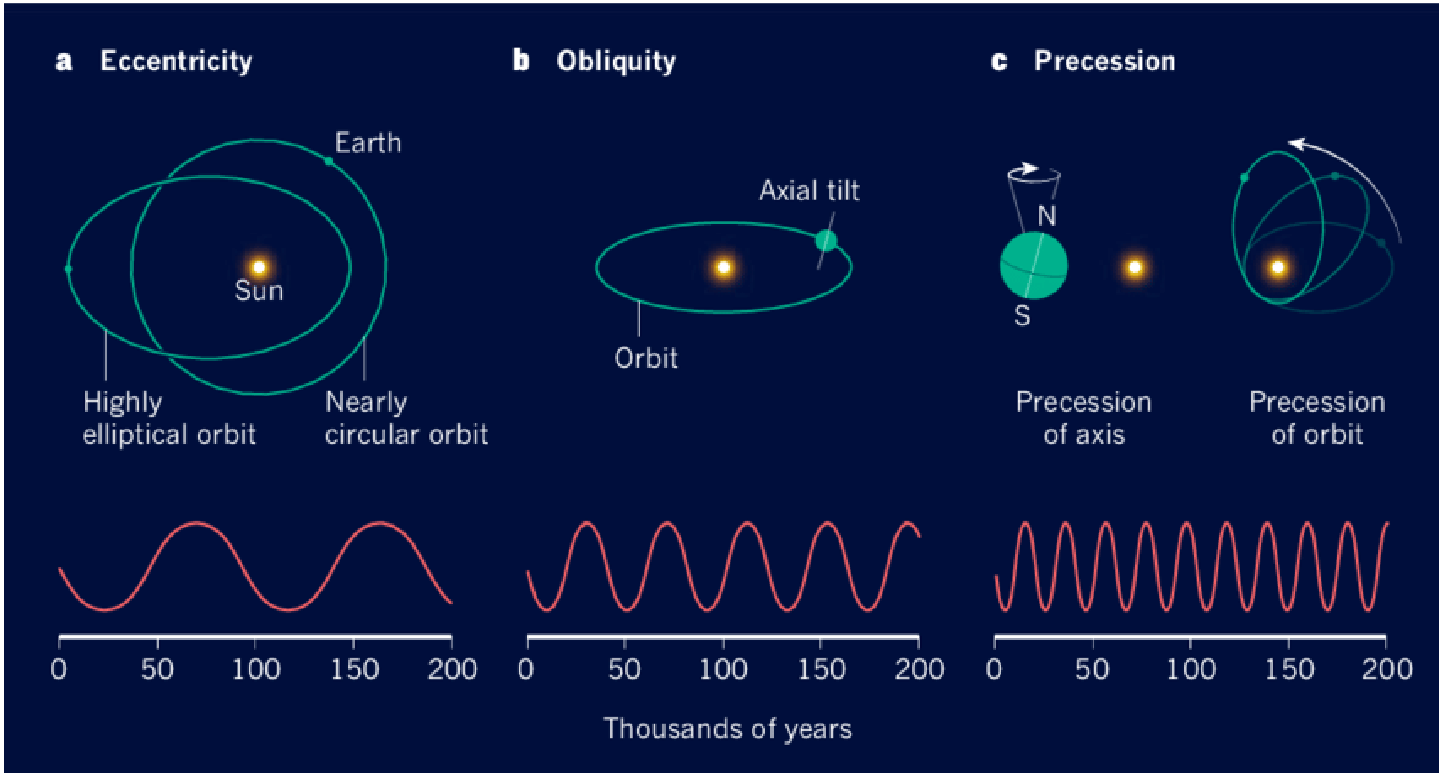
Will summers then be hotter or cooler than now?

hotter

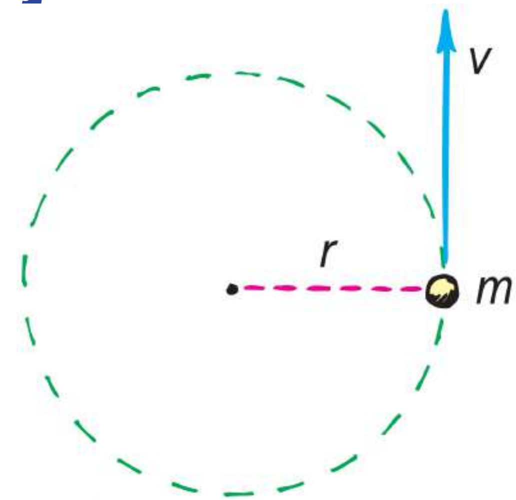
Milankovitch cycles:

In addition to precession, the amount of tilt (the obliquity) and the eccentricity of the orbit change.

These cause natural climate changes to occur.



Angular Momentum: Simple objects



- Examples:
  – Whirling ball at the end of a long string
  – Planet going around the Sun

- For an object that is small compared with the radial distance to its axis, magnitude of

Angular momentum = mass x tangential speed x radius

L = mvr

How is this different from linear momentum?

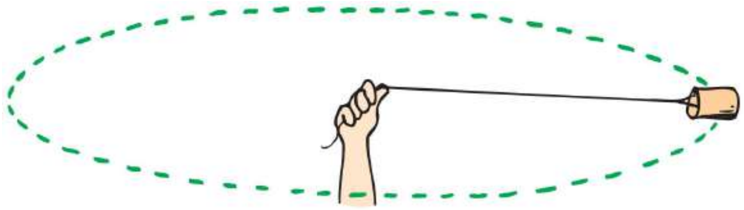
p = mv

L has an extra ***r***

Ex. Using L = mvr

A can with a mass of 0.5 kg is swung around at a radius of 1 m at a speed of 4 m/s. Calculate the angular momentum L of the can.

$$L = mvr$$
$$= (0.5\ \text{kg})(4\ \text{m/s})(1\ \text{m})$$
$$= 2\ \text{kgm}^2/\text{s}$$



Recalculate L for the same mass but with r = 0.5 m and v = 8 m/s.

$$L = mvr$$
$$= (0.5\ \text{kg})(8\ \text{m/s})(0.5\ \text{m})$$
$$= 2\ \text{kgm}^2/\text{s}$$

Lesson:
If r is halved, what happens to L if v is doubled?
no change

Questions

1. Distinguish between linear and angular momentum.

2. What is the law of inertia for rotating systems in terms of angular momentum.

Problems with: angular momentum = mvr

3. Calculate the angular momentum of an 80-kg person on sits 2 m from the center of a rotating platform and has a tangential speed of 3 m/s.

4. Repeat the above problem if her speed doubles.