From last time...

Inertia:

tendency of body to continue in straight-line motion at constant speed unless disturbed.

Superposition:

object responds independently to separate disturbances

- Galileo used these properties to determine:
  - Light and heavy objects fall identically.
  - Falling time proportional to square root of falling distance.

Would like to demonstrate these properties by experiment.

1

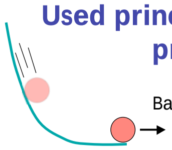
Improved experiments

- Penny and cotton ball experiment didn't work because of force from the air.
  - Answer: Perform a better experiment that takes out the effect of the air.
  - In vacuum vessel or on the moon.
- Falling ball experiment might also have other influences.
  - Height of ball when dropped.
  - Velocity of ball when dropped.
  - Slope of ramp needs to be the same.
  - Measuring position of ball when it lands.

Should be able to improve all of these things!

2

Used principle of superposition and principle of inertia



Ball leaves ramp with constant horizontal speed

After leaving ramp, it continues horizontal motion at some constant speed *s* (no horizontal disturbances)

But gravitational disturbance causes change in vertical motion (the ball falls downward)

For every second of fall, it moves to the right *s* meters

Determine falling time by measuring horizontal distance!

An equation

From this, Galileo determined that the falling time varied proportional to the square root of the falling distance.

$$\text{Falling time} \propto \sqrt{\text{Falling distance}}$$

Falling time = *t*

Falling distance = *d*

$$d \propto t^2$$

$$d = ct^2$$

How much longer does it take?

I drop two balls, one from twice the height of the other. The time it takes the higher ball to fall is how much longer than the lower ball?

A. Two times longer
B. Three times longer
C. Four times longer
D. Square root of 2 longer

Details of a falling object

- Just how does the object fall?
- Apparently independent of mass, but how fast?

- Starts at rest (zero speed), ends moving fast
  - Hence speed is not constant.
- 1) Falling time increases with height.
- 2) Final speed increases with height.

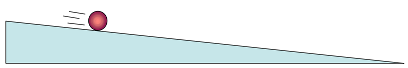
We understand how 1 works. Lets investigate 2

6

Slow motion, in 1632

- The inclined plane
  - 'Redirects' the motion of the ball
  - Slows the motion down
  - But 'character' of motion remains the same.

I assume that the speed acquired by the same movable object over different inclinations of the plane are equal whenever the heights of those planes are equal.



How can we show this?

- Focus on the speed at end of the ramp.
- Galileo claimed this speed independent of ramp angle, as long as height is the same.

Falling speed

As an object falls, it's speed is

A. Constant
B. Increasing proportional to time
C. Increasing proportional to time squared

Constant acceleration

- In fact, the speed of a falling object increases uniformly with time.
- We say that the **acceleration** is constant
- Acceleration:

$$\frac{\text{Change in speed}}{\text{change in time}} \qquad a = \frac{\Delta s}{\Delta t}$$

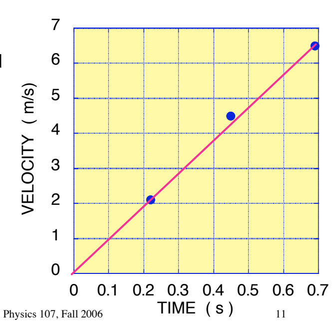
Units are then (meters per second)/second

=(m/s)/s abbreviated m/s^2

Falling object instantaneous speed vs time

- Instantaneous speed proportional to time.
- So instantaneous speed increases at a constant rate
- This means constant acceleration
- *s=at*

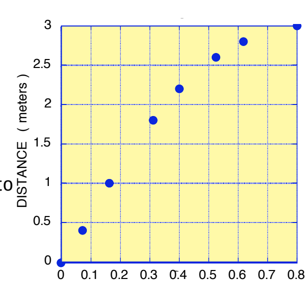
$$\text{accel} = \frac{\text{change in speed}}{\text{change in time}} = \frac{6.75 \ m/s}{0.69 \ s} = 9.8 \ m/s/s = 9.8 \ m/s^2$$



Distance vs time for falling ball

- Position vs time of a falling object
- This completely describes the motion
- Distance proportional to time squared.

$$d = \left(4.9 \ m/s^2\right)t^2$$



Galileo's experiment

A piece of wooden moulding or scantling, about 12 cubits [about 7 m] long, half a cubit [about 30 cm] wide and three finger-breadths [about 5 cm] thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as possible, we rolled along it a hard, smooth, and very round bronze ball.

For the measurement of time, we employed a large vessel of water placed in an elevated position; to the bottom of this vessel was soldered a pipe of small diameter giving a thin jet of water, which we collected in a small glass during the time of each descent... the water thus collected was weighed, after each descent, on a very accurate balance; the difference and ratios of these weights gave us the differences and ratios of the times...

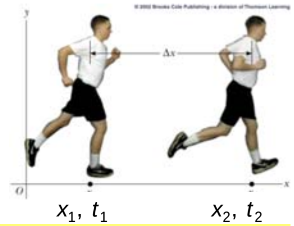
Using this method, Galileo very precisely determined a law that explained the motion

Quantifying motion: Distance and Time

- A moving object changes its position with time.

x_1 = pos. at time t_1

x_2 = pos. at time t_2



e.g.
at 10:00 am, I am 3 meters along the path (x_1=3 m, t_1=10:00 am)
at 10:00:05 am, I am 8 meters along the path (x_2=8 m, t_1=10:00:05 am)

My position at all times completely describes my motion

The *average* speed

$$\text{Average speed} = \frac{\text{distance traveled}}{\text{traveling time}}$$

As an equation:

Distance traveled = d
Traveling time = t
Average speed = $\bar{s}$

$$\bar{s} = \frac{d}{t}$$

Could also write $d = \bar{s}t$

So knowing average speed lets us find distance traveled

BUT maybe I walked 0 meters in the first second and then 5 meters in 4 seconds. Sometimes need instantaneous speed.

Think about this one:

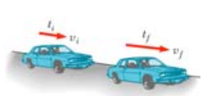
You increase your speed uniformly from 0 to 60 mph. This takes 6.0 seconds.
Your average speed is.

A. 10 mph
B. 30 mph
C. 40 mph
D. 60 mph

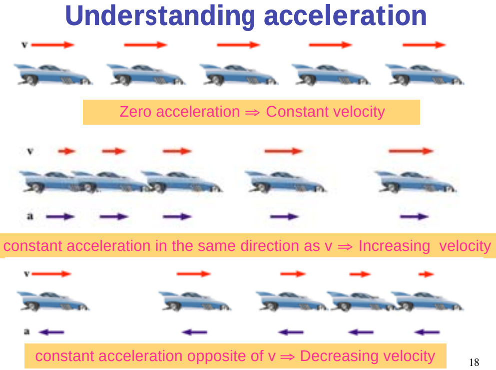
Acceleration

Acceleration is the rate at which velocity changes:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time to make the change}}$$



Understanding acceleration

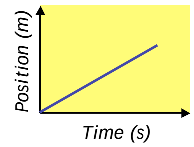


Major points

- position: coordinates of a body
- velocity: rate of change of position
  - average : $\frac{\text{change in position}}{\text{change in time}}$
  - instantaneous: average velocity over a very small time interval
- acceleration: rate of change of velocity
  - average: $\frac{\text{change in velocity}}{\text{change in time}}$
  - instantaneous: average acceleration over a very small time interval

Just to check...

A car's **position** on a highway is plotted versus time. It turns out to be a straight line. Which of these statements is true?



A. Its acceleration is negative

B. Its acceleration is positive

C. Its acceleration is zero

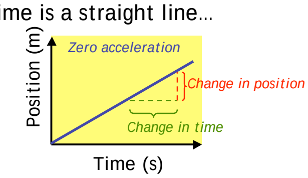
D. Its velocity is zero

Why *a*=0?

- Position vs time is a straight line...

x = vt

Constant velocity



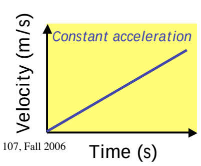
- ...means constant velocity (= $\frac{\text{change in position}}{\text{change in time}}$)
- Constant velocity means zero acceleration

What about constant acceleration?

- Acceleration = $\frac{\text{change in velocity}}{\text{change in time}}$
- Constant acceleration:
  - For every time interval (say, 1 second), the velocity chnages by the same amount.
  - a>0 gives a uniformly *increasing* velocity:

v = at

Constant acceleration



Question

You are traveling at 60 miles per hour. You apply the brakes, resulting in a constant *negative* acceleration of -10 mph / second.

How many seconds does it take to stop?

A. 10 seconds

B. 6 seconds

C. 3 seconds

Velocity change is 10 mph for every second. Takes six seconds to decrease the velocity to zero

Questions

How far does the car go during that time?

A. 0.1 mile

B. 0.2 mile

C. 0.05 mile

Since speed changes uniformly with time (from 60 mph to 0 mph), so average speed is 30 mph.

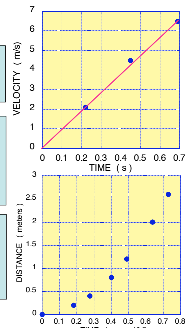
Distance = average speed x time
= (30 miles/hour) x (6 seconds) =
= (30 miles/hour) x (1/600 hr) = 1/20 mile

Galileo Uniform acceleration from rest

Acceleration = const = a = 9.8 m/s^2

Velocity = (acceleration)x(time)
= at
Uniformly increasing velocity

Distance = (average vel)x(time)
= $(1/2)at \times t = (1/2)at^2$



Falling object: constant acceleration

- Falling objects have constant acceleration.
- This is called the acceleration of gravity
  9.8 m/s/s = 9.8 m/s^2
- But why does gravity result in a constant acceleration?
- Why is this acceleration independent of mass?

Tough questions

- These are difficult questions.
  Maybe not completely answered even now.
- But tied into a more basic question:
  - What causes acceleration?
  - Or, how do we get an object to move?

A hot topic in the 17th century.

Descartes (*cogito ergo sum*) was a major player in this.

Descartes' view…

- Motion and rest are primitive states of a body without need of further explanation.
- Bodies only change their state when acted upon by an external cause.

This is similar our concept of inertia

Inertia and momentum

- Principle of inertia: object continues at constant velocity unless disturbed.
- A disturbance will change the velocity.
  This change in velocity is acceleration.
- Could start an object moving that is at rest, or stop an object that is moving.

Different types of objects

- Objects with lots of inertia don't change motion as much as lighter objects subject to the same disturbance.
- Inertia measures the degree to which an object at rest will stay at rest.
- An object with lots of inertia is difficult to accelerate (acceleration = change in velocity).

demo

Quantifying Inertia: Momentum

- Same disturbance applied to different objects results in different velocities (e.g. hitting bowling ball and golf ball w/golf club).
- But the product **mass × velocity** *is* the same (e.g. for the bowling ball and the golf ball).
- Momentum = (mass)×(velocity)

Descartes also said…

That a body, upon coming in contact with a stronger one, loses none of its motion; but that, upon coming in contact with a weaker one, it loses as much as it transfers to that weaker body

So for Descartes, the total amount of 'motion' is always the same.

We call the amount of motion 'momentum', and Descartes law as 'conservation of momentum'

Momentum conservation

- Can easily describe interactions of objects.
- The total momentum (sum of momenta of each object) of the system is always the same.
- We say that momentum is conserved.
- Momentum can be transferred from one object to the other, but it does not disappear.

Next Time

- Descartes was able to move beyond the complicated details of collisions to some basic governing principles.
- Next time, look at how Newton extended these ideas with his three laws of motion.
- Builds on Galileo and Descartes, but includes the concept of a force.