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# Chapter 3: Linear Motion

## Preliminaries

- Linear motion is motion in a straight line.

- Note that motion is **relative**: e.g. your paper is moving at 107 000 km/hr relative to the sun. But it is at rest relative to you.

  Unless otherwise stated, when we talk about speed of things in the environment, we will mean relative to the Earth's surface.

# Speed

- Speed measures “how fast” :

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

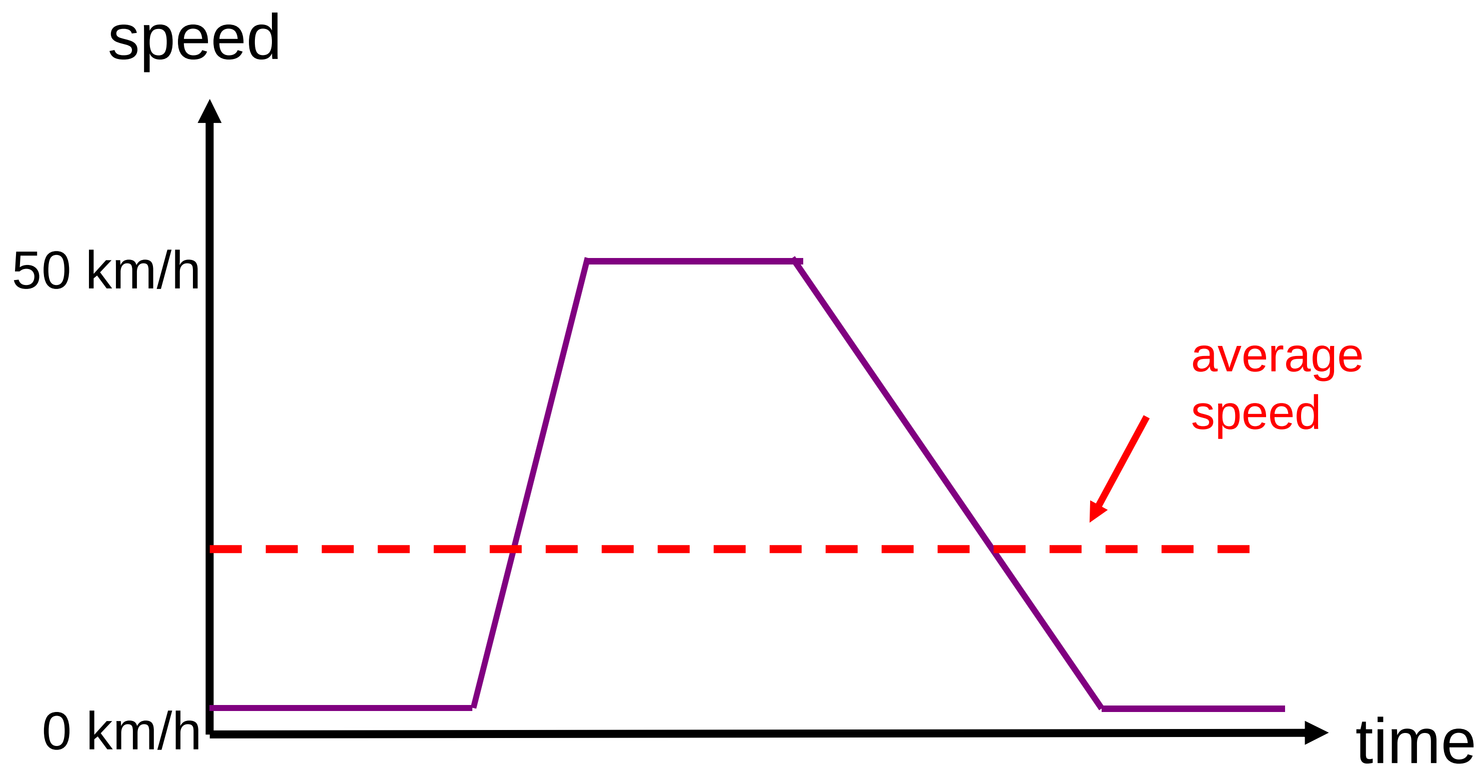
Units: eg. km/h, mi/h (or mph), m/s

meters per second, standard units for physics

# Instantaneous vs Average Speed

Things don't always move at the same speed:

A car starts at 0 km/h, speed up to 50 km/h, stay steady for a while, and then slow down again to stop.



Average speed of an object: *Total distance traveled divided by the time it takes to travel this distance.*

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

Instantaneous speed of an object: *Average speed during an infinitesimally short time interval*

$$\text{Inst speed} = \lim_{\text{time interval} \to 0} \frac{\text{total distance traveled}}{\text{time interval}}$$

Constant speed means steady speed.
An object with constant speed does not speed up or dow

Eg. Carl Lewis once ran 100m in 9.92s.

- What was his average speed during that run?

Average speed = dist/time = 100m/9.92s = 10.1 m/s

- How much distance did he cover per second, on average?

10.1 m, by definition of average speed

- How did this relate to his top speed?

Top speed is more (actually about 10% over !)

# Velocity

- Velocity is **speed** in a given **direction**
- *velocity is a vector quantity*
- *speed is a scalar quantity*

Constant velocity: Constant speed and constant direction.

- Note that an object may have constant speed but a changing velocity

Eg. Whirling a ball at the end of a string, in a horizontal circle – same speed at all times, but changing directions. Or, think of a car rounding a bend, speedometer may not change but velocity is changing, since direction is.

# Clicker Question

If a car is moving at 90km/h and it rounds a corner, also at 90km/h, does it mantain a constant speed?

A) Yes

B) No

If a car is moving at 90km/h and it rounds a corner, also at 90km/h, does it mantain a constant speed?

A) Yes!!

Because the cars rounds the corner at 90 km/h, the speed is not changing!!

# Clicker Question

If a car is moving at 90km/h and it rounds a corner, also at 90km/h, does it mantain a constant velocity?

A) Yes
B) No

If a car is moving at 90km/h and it rounds a corner, also at 90km/h, does it mantain a constant velocity?

B)No !!

In the moment that the car rounds the corner is changing the direction of the motion, then the velocity is not constant

# Acceleration

- Measures how quickly **velocity changes**:

$$\text{Acceleration} = \frac{\text{change of velocity}}{\text{time interval}}$$

E.g. Suppose we are driving and in 1 second, we steadily increase our velocity from 30 km/h to 35 km/h, and then to 40 km/h in the next second.

$$\text{Acceleration} = \frac{35\text{km/h}-30\text{km/h}}{1\text{ s}} = 5\text{km/(h s)}$$

- In this case the change in velocity is 5km/h every second
- Note acceleration refers to: decreases in speed, increases in speed, and/or changes in direction

# Clicker Question

What is the acceleration of a cheetah that zips past you at a constant velocity of  60 mph?

A) 0

B) $60\ mi/h^2$

C) Not enough information given to answer problem

D) None of the above

What is the acceleration of a cheetah that zips past you going at a constant velocity of 60 mph?

A) 0

B) 60 mi/h$^2$

C) Not enough information given to answer problem

D) None of the above

Constant velocity means no change in velocity i.e. no acceleration

# Questions

a) A certain car goes from rest to 100 km/h in 10 s. What is its acceleration?

10 km/h.s *(note units!)*

b) In 2 s, a car increases its speed from 60 km/h to 65 km/h while a bicycle goes from rest to 5 km/h. Which undergoes the greater acceleration?

The accelerations are the same

acceleration = $(\Delta v)/(\Delta t)$ = (5 km/h)/(2 s) = 2.5 km/h.s

c) What is the average speed of each vehicle in that 2 s interval, if we assume the acceleration is constant ?

For car: 62.5 km/h

For bike: 2.5 km/h

# Free-Fall

- Free-fall: is when object falls under influence of gravity alone (no air resistance, or any other restraint).

Since this acc. is due to gravity, call it *g*. Near surface of Earth, ***g* = 9.8 m/s²**

That means the velocity changes 9.8m/s every second

For simplicity we can write **g** = 10 $m/s^2$

i.e. velocity gain of 10 meters per second, per second

Eg. Free-fall from rest

| Time(s) | Velocity(m/s) |
|---|---|
| 0 | 0 |
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| .. | .. |
| t | 10 t |

*Note! We rounded g to 10 $m/s^2$ in the table…*

3. Hewitt, printed courte

# Free-Fall

Free-fall: this acceleration is experienced by all the objects near to the surface of the Earth and is independent of its mass.

Free-fall: since acceleration is also a vectorial quantity, the direction of g in pointing downwards.

If an object is falling is gaining velocity

- What happens if object is thrown upwards, instead of being dropped?

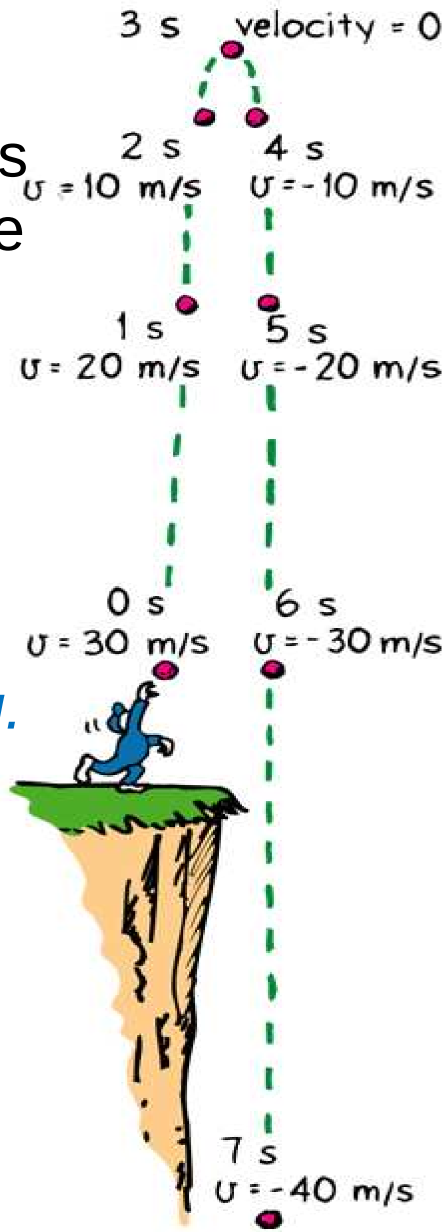
Once released, it continues to move upwards for a while, then comes back down. At the top, its instantaneous speed is zero (changing direction); then it starts downward just as if it had been dropped from rest at that height.

-- As it rises, it slows down at a rate of *g.*

-- At the top, it has zero velocity as it changes its direction from up to down.

-- As it falls, it speeds up at a rate of *g.*

-- Equal elevations have equal speed (but opposite velocity)



# Free-fall continued:

**How far?**

i.e. what distance is travelled?

From the sketch before, we see distance fallen in equal time intervals, increases as time goes on.

Actually, one can show (appendix in book), for any uniformly accelerating object,

distance travelled, ***d* = ½ (acceleration x time x time)**

So in free-fall :

$$d = \frac{1}{2} g t^2$$

# Free-fall continued:

…in free-fall : $\boldsymbol{d = \frac{1}{2} g t^2}$

Free-fall:

| Time(s) | Distance fallen(m) |
|---|---|
| 0 | 0 |
| 1 | 5 |
| 2 | 20 |
| 3 | 45 |
| .. | .. |
| $t$ | $\frac{1}{2}\, 10\, t^2$ |

Notice that in the 1st second, the distance is 5m, so the average speed is 5 m/s.

On the other hand, the instantaneous speed at the beginning of the 1st sec ( ie t=0) is 0 and at the end of 1st sec is v = 10 m/s (earlier table).

*So, in this case, the average speed is the average of the initial and final speeds*.

# Application: “Hang-time” of jumpers

- Michael Jordan’s best hang-time was 0.9 s – this is the time the feet are off the ground. Let’s round this to 1 s. How high can he jump?

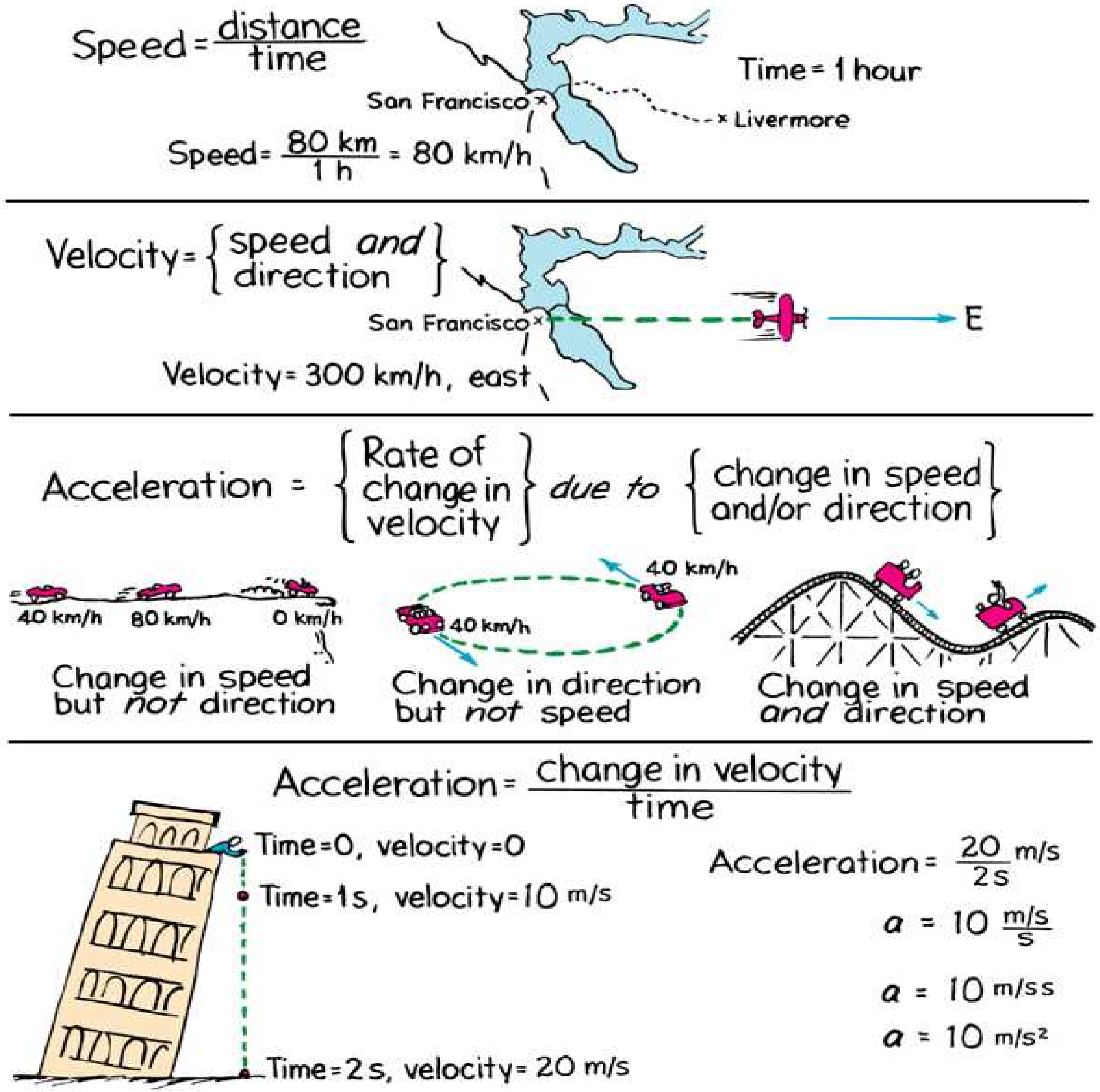
Use $d = \frac{1}{2} g t^2$ . For 1 s hang-time, that’s ½ s up and ½ s down. So, substituting

$d = \frac{1}{2} (10) (1/2)^2 = \underline{1.25\ m}$

This is about 4 feet!

Note that good athletes, dancers etc may appear to jump higher, but very few can raise their *center of gravity* more than 4 feet.

# Summary of definitions



# Clicker Question

Can an object have zero velocity but non-zero acceleration?

A) Yes

B) No

Can an object have zero velocity but non-zero acceleration?

A) Yes

B) No

Eg. Throw a ball up in the air – at the top of its flight, as it turns around it has momentarily zero speed but is changing its direction of motion, so has non-zero acceleration