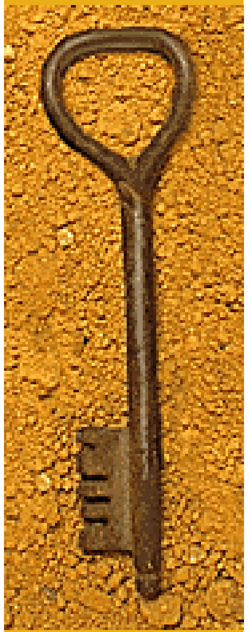
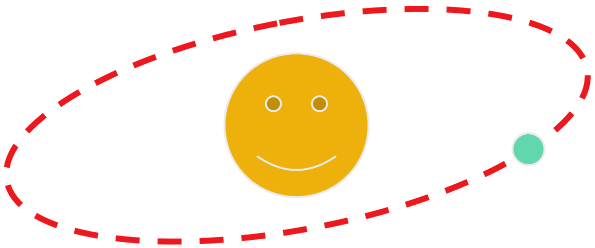


3 Linear Motion

- Speed
- Velocity
- Acceleration
- Free Fall

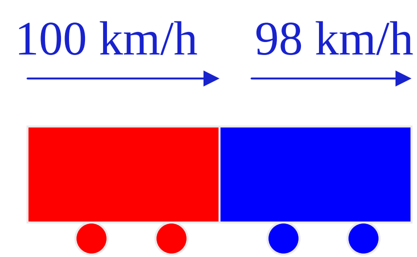
Motion is Relative

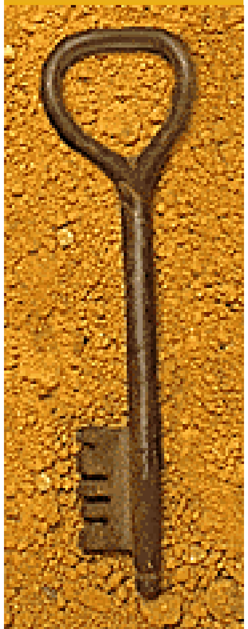
- When we discuss the motion of something, we describe motion *relative* to something else.
- Unless stated otherwise, when we discuss the speeds of things in our environment we mean *relative* to the surface of the Earth.



When sitting on a chair, your speed is zero relative to the Earth but 30 km/s relative to the sun

Question: What is the impact speed when a car moving at 100 km/h bumps into the rear of another car traveling in the same direction at 98 km/h?



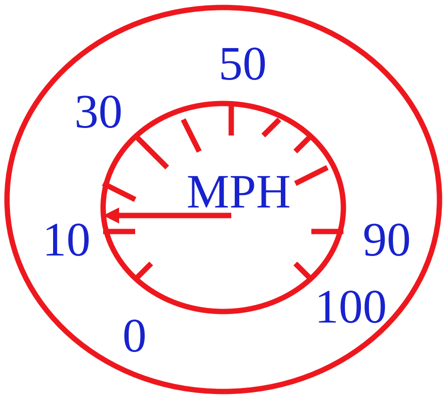


Speed

- Speed is a measure of *how fast* something moves.
- Speed is a *scalar* quantity, specified only by its magnitude.
- Two units of measurement are necessary for describing speed: units of *distance* and *time*
- Speed is defined as the distance covered per unit time: speed = distance/time
- Units for measuring speed: km/h, mi/h (mph), m/s

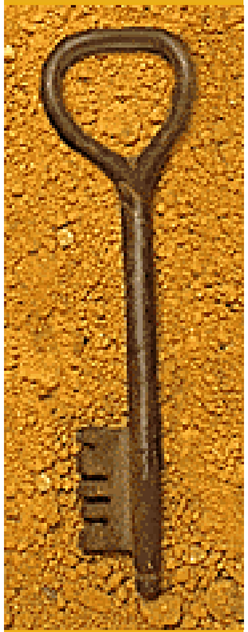
Instantaneous Speed

- The speed at any instant is the *instantaneous speed*.
- The speed registered by an automobile speedometer is the instantaneous speed.



Average Speed

- Average speed is the *whole distance* covered divided by *the total time* of travel.
- General definition:
  - Average speed = total distance covered/time interval
- Distinguish between instantaneous speed and average speed:
  - On most trips, we experience a variety of speeds, so the average speed and instantaneous speed are often quite different.
  - Is a fine for speeding based on ones average speed or instantaneous speed?

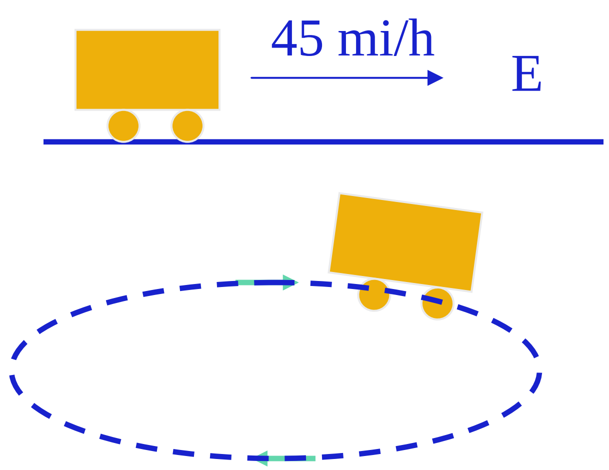


Finding Average Speed

- Example 1: If we travel 320 km in 4 hours, what is our average speed? If we drive at this average speed for 5 hours, how far will we go?
  - Answer: v_{avg} = 320 km/4 h = 80 km/h.
  - $d = v_{avg}$ x time = 80 km/h x 5 h = 400 km.
- Example 2: A plane flies 600 km away from its base at 200 km/h, then flies back to its base at 300 km/h. What is its average speed?
  - Answer:
  - total distance traveled, d = 2 x 600 km = 1200 km;
  - total time spent (for the round trip), t = (600 km/200 km/h) + (600 km/300 km/h) = 3 h + 2 h = 5 h.
  - Average speed, $v_{\text{avg}} = d/t$ = 1200 km/5 h = 240 km/h.
- Tip: start from the *general definition* for average speed!

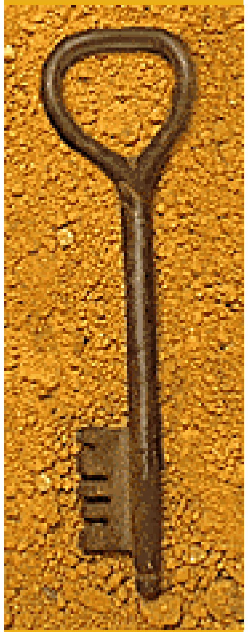
Velocity

- Velocity is speed in a given direction; when we describe *speed and direction* of motion, we are describing *velocity*.
- Velocity = speed and direction; velocity is a *vector*.
- Constant velocity = constant speed *and* no change in direction



Circle around the race track at 45 mi/h

Question: which car is moving with a constant velocity? Constant speed? Why?

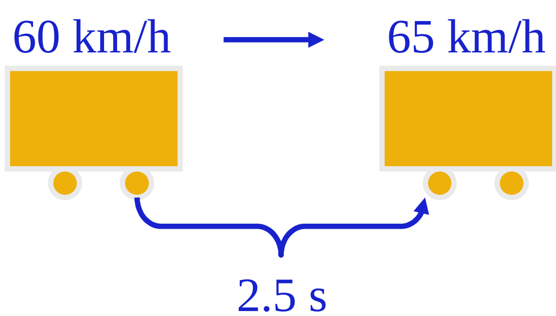


Acceleration

- Acceleration tells you *how fast (the rate) velocity changes:*
  - Acceleration = change in velocity/time interval
  - Acceleration is *not* the total change in velocity; it is the *time rate* of change!
- Changing the velocity:
  - Changing its *speed; increase or decrease in speed*
  - Changing its *direction*
  - Or changing *both* its speed and direction
- Acceleration is a *vector* and is specified by both its magnitude and its direction.
  - When the direction of acceleration is the same as that of motion, it increases the speed;
  - When the direction of acceleration is opposite that of motion, it decreases the speed-deceleration.

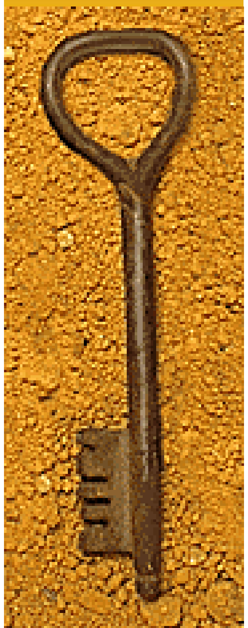
Finding Acceleration

- Example 1: In 2.5 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? What is the acceleration of each vehicle?

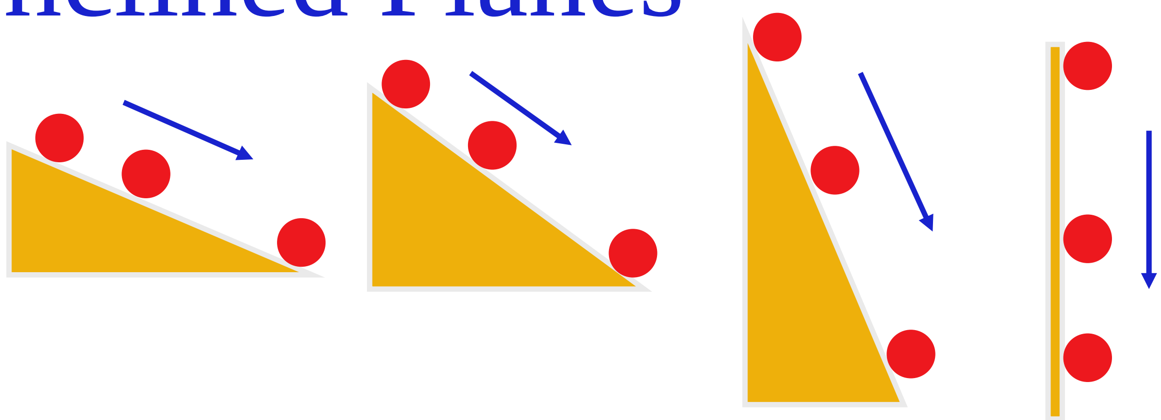


Acceleration of the car = (65 km/h - 60 km/h)/2.5 s = 2 km/h·s.

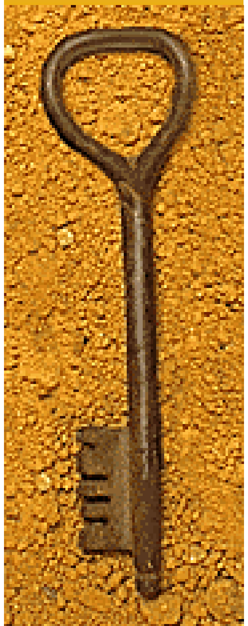
Acceleration of the bike= (5 km/h - 0 km/h)/2.5 s = 2 km/h·s.



Acceleration on Galileo's Inclined Planes



- Galileo's findings:
  - A ball rolls down an inclined plane with unchanging acceleration.
  - The greater the slope of the incline, the greater the acceleration of the ball.
  - If released from rest, the instantaneous speed of the ball at any given time = acceleration x time.
  - What is its acceleration if the incline is vertical?



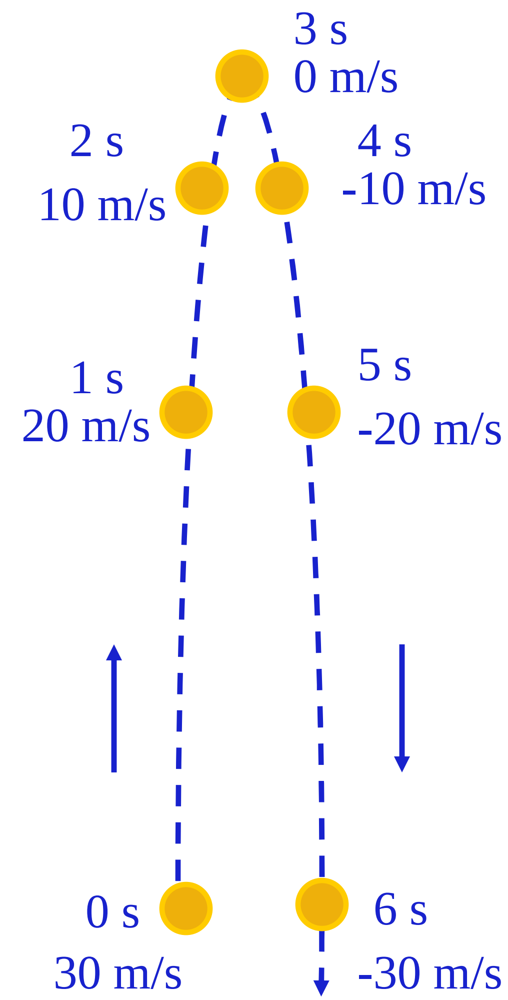
Free Fall

- Things fall because of *gravity*.
- When a falling object is free of all restraints-no friction, air resistance, and falls under gravity alone, the object is in a state of *free fall*.
- For free falling objects, regardless of their weight and size, acceleration is the *same*, $g = 9.8\ m/s^2$(or ~ $10\ m/s^2$).

Time of Fall (s)	Velocity (m/s)
0	0
1	10
2	20
t	$10\ t$

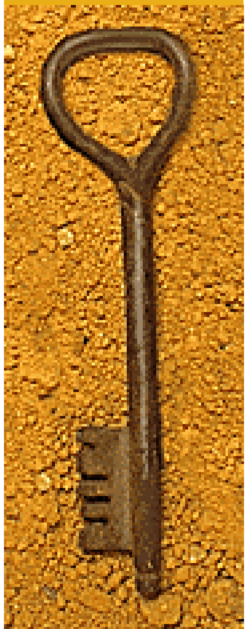
A Ball Thrown Straight upward

- Once released, it continues to move upward for a while and then comes back down.
- During its upward motion, it decelerate at about 10 m/s per second.
- At the highest point, in the transition from being moving upward to moving downward, its instantaneous speed is zero. Is it in equilibrium at this point?
- Then it starts straight downward.



How Far

- Galileo’s finding from the inclined planes experiment:
  - The distance traveled by a *uniformly accelerating object* is proportional to *the square of the time*: Distance traveled = (1/2) x (acceleration) x (time^2).
  - For a freely falling object, $d = gt^2/2$.
- Consider the case when air resistance is *not negligible*:
  - Objects of different weight or size may fall with unequal accelerations, e.g. a feather and a stone.
  - However, the relationship $v = gt$ and $d = gt^2/2$ can be used to a very good approximation for most objects falling in air from rest.



Calculating Distance Using Free Fall Formulas

- Example: A cat steps off a ledge and drops to the ground in 1/2 second.
  - (a) What is its speed on striking the ground?
  - (b) What is its average speed during the 1/2 second?
  - (c) How high is the ledge from the ground?
- Answer:
  - (a) Speed: $v = gt$ = (10 m/s^2) x (1/2 s) = 5 m/s.
  - (b) Average speed: v_{avg} = (initial v + final v)/2 = (0 m/s + 5 m/s)/2 = 2.5 m/s (this formula only applies to the case of constant acceleration).
  - (c) Distance: $d = gt^2/2$ = (1/2) x (10 m/s^2) x (1/4 s^2) = 1.25 m.

Homework

- Chapter 3, Page 52, Exercises: # 8, 18, 25, 27.