One-dimensional kinematics, continued

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2025 W34[1]

[1]Phys 20.01 Mod 1. All figures are from Urone (2022) unless noted.

Agenda

Motion with constant acceleration ⭕

Freely falling objects 🪶

Quiz time 🕐

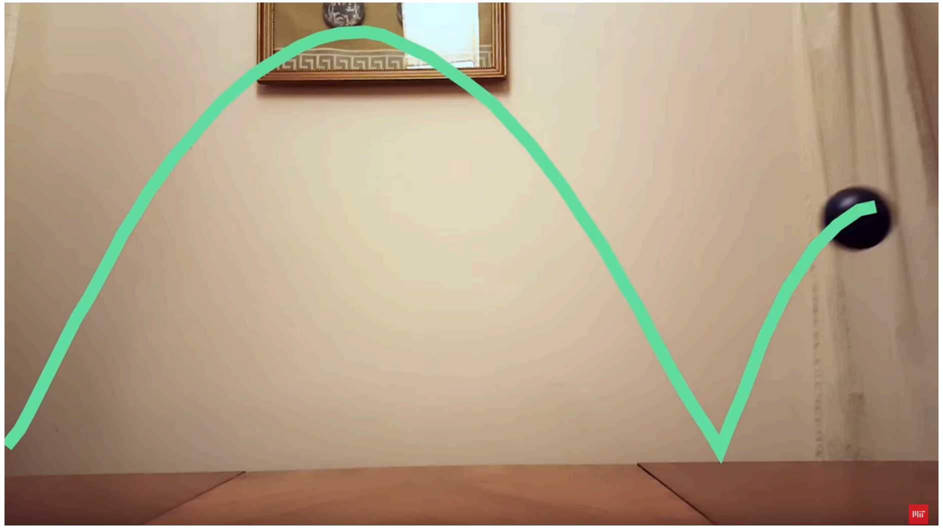
Quick recap 🕐

All about motion

- Motion is everywhere (obvious and subtle)
- Motion is relative: an object relative to another
- Studying motion: kinematics is how, dynamics is why

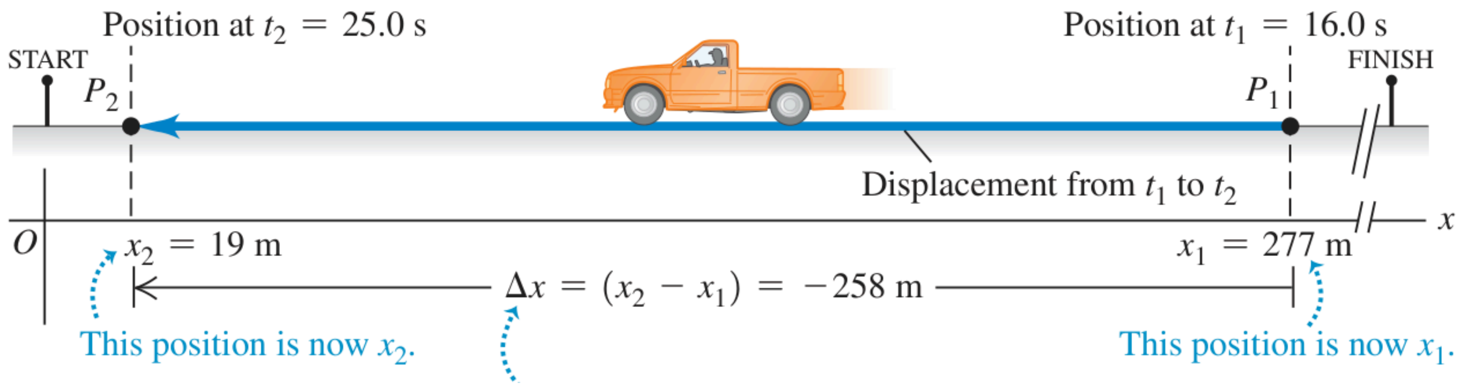
$$\vec{F} = m\vec{a}$$

$$\text{why} \leftrightarrow \text{how}$$



Displacement

- Position is where an object is at any particular time
- Distance traveled is the total length of the path traveled between two positions
- Displacement is the change in position: $\Delta x = x_f - x_0$



Velocity

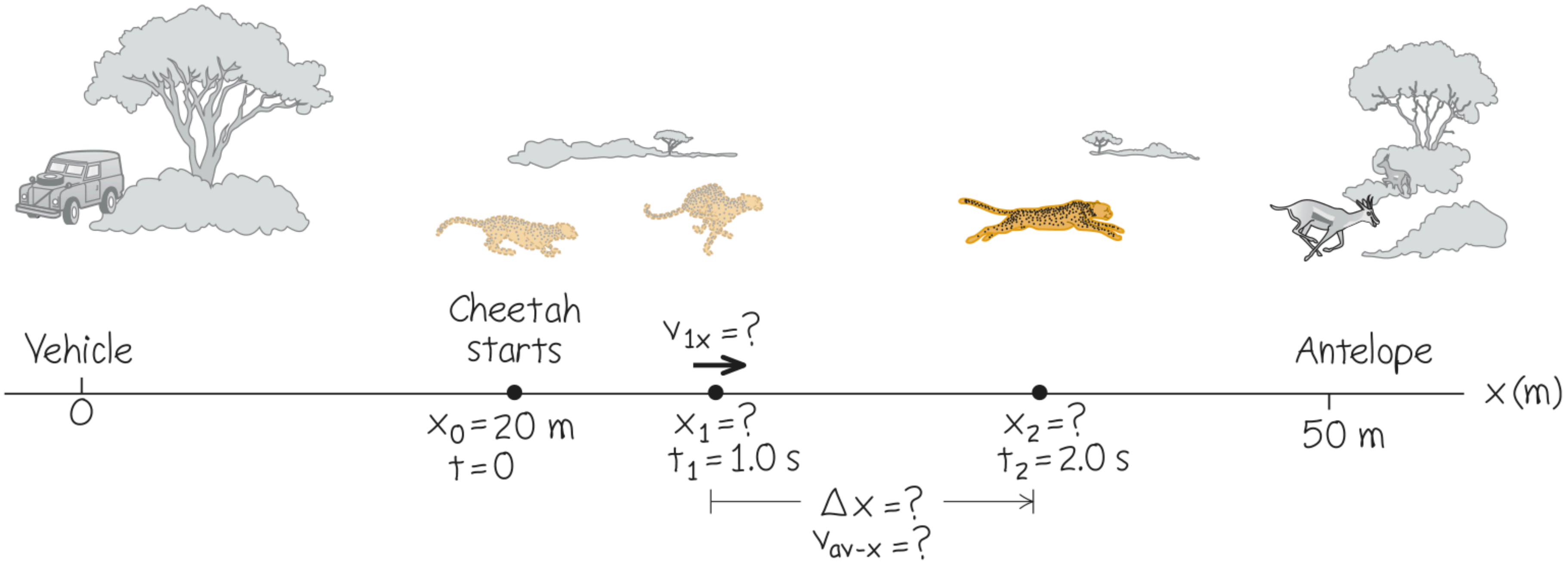
- Time is in terms of change. Elapsed time is $\Delta t = t_f - t_0$
- Average speed is total distance traveled divided by travel time, and is not the magnitude of average velocity
- Instantaneous speed is speed at an instant of time, and is the magnitude of instantaneous velocity
- (Average) velocity $\overline{v}$ is displacement divided by travel time: $\overline{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_0}{t_f - t_0}$
- Instantaneous velocity v is velocity at a specific instant: $v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{\mathrm{d}x}{\mathrm{d}t}$

Acceleration

- (Average) acceleration $\overline{a}$ is the rate at which velocity changes: $\overline{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$
- Instantaneous acceleration a is the acceleration at a specific instant in time: $a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{\mathrm{d}v}{\mathrm{d}t}$
- It is a vector so it can be caused by either a change in the magnitude or the direction of the velocity
- Deceleration is an acceleration in the opposite direction to an object's motion (velocity), causing it to slow down

Oh dear, antelope!

Example. A cheetah is crouched 20 m to the east of a vehicle. At time $t = 0$, the cheetah begins to run due east toward an antelope that is 50 m to the east of the vehicle. During the first 2.0 s of the chase, the cheetah's x-coordinate varies with time according to the equation $x = 20 \ \ \mathrm{m} + (5.0\mathrm{m/s}^2)t^2$.
(a) Find the cheetah's displacement between $t_1 = 1.0$ s and $t_2 = 2.0$ s. (b) Find its average velocity during that interval.
(c) Find its instantaneous velocity at $t_1 = 1.0$ s by taking $\Delta t = 0.1$ s, then 0.01 s, then 0.001 s.



1. Point axis in direction cheetah runs, so that all values will be positive.
2. Place origin at vehicle.
3. Mark initial positions of cheetah and antelope.
4. Mark positions for cheetah at 1 s and 2 s.
5. Add the known and unknown quantities.

Motion with constant acceleration ⭕

Testing humans at high accelerations

In experiments carried out by the US Air Force in the 1940s and 1950s, humans riding a rocket sled could withstand accelerations as big as 440 m/s^2.

Photos 1-3 show Air Force physician John Stapp speeding up from rest to 188 m/s (678 km/h) in just 5 s.

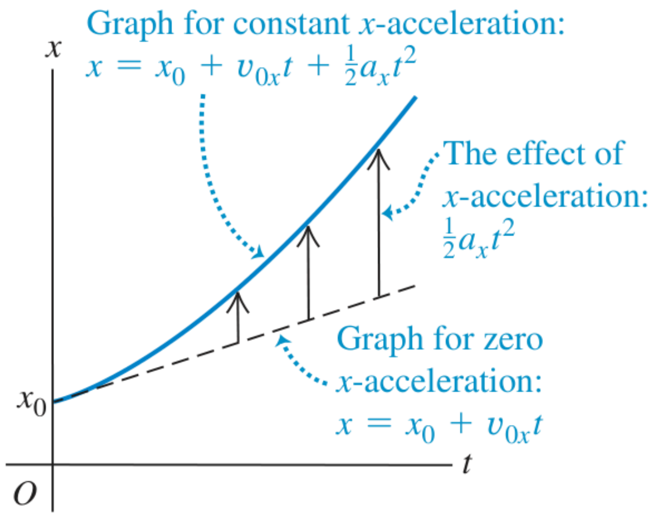
Kinematic equations

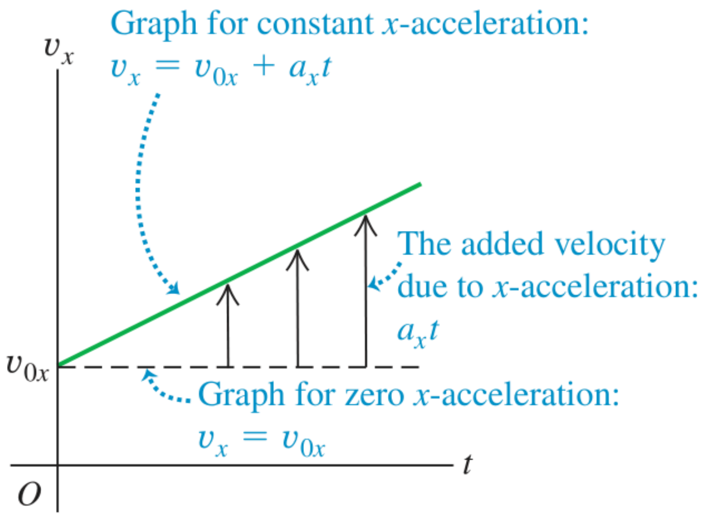
- When acceleration is constant, these **kinematic equations** relate the position x and velocity v at any time t to initial position x_0, initial velocity v_0 (both measured at time $t_0 = 0$), and acceleration a

$$v = v_0 + at, \qquad x = x_0 + v_0 t + \frac{1}{2}at^2, \qquad v^2 = v_0^2 + 2a(x - x_0),$$

$$x - x_0 = \overline{v}t, \qquad \overline{v} = \frac{1}{2}(v_0 + v),$$

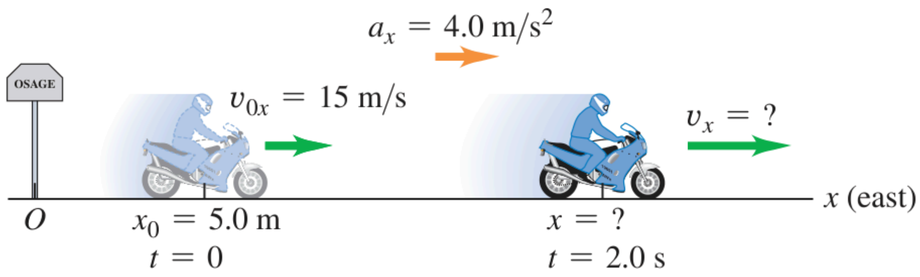
- Again, we take acceleration to be constant so $\bar{a} = a$ at all times, and initial time to be zero
- In vertical motion, y takes the place of x





Just motorcyclin'

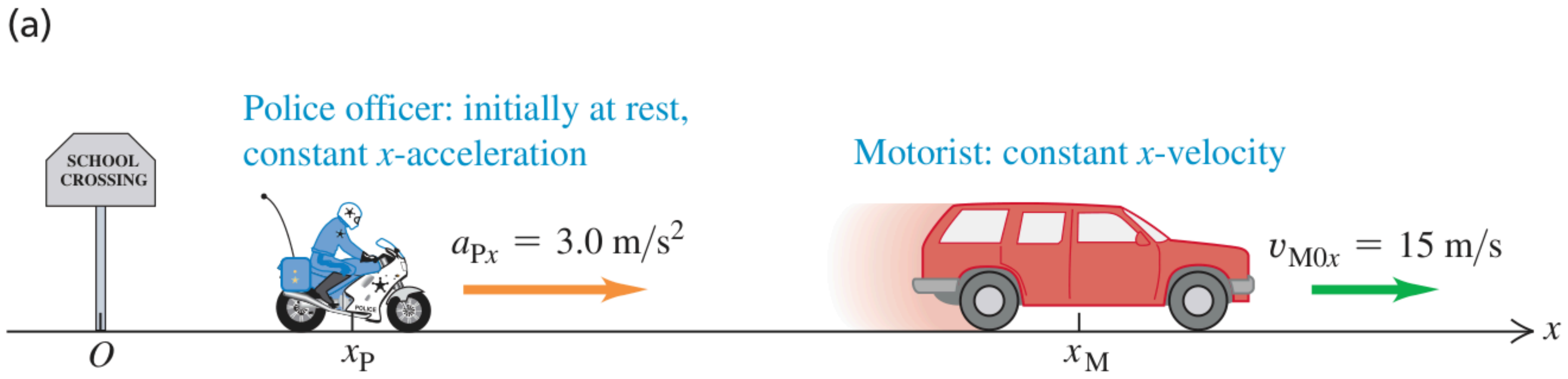
Example. A motorcyclist heading east through a small town accelerates at a constant 4.0 m/s^2 after he leaves the city limits. At time $t = 0$, he is 5.0 m east of the city-limits signpost while he moves east at 15 m/s. (a) Find his position and velocity at $t = 2.0$ s. (b) Where is he when his speed is 25 m/s?

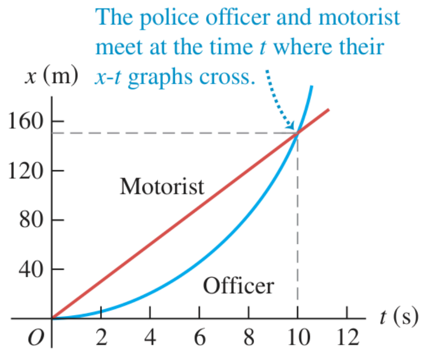


I am speed

Example. A motorist traveling at a constant 15 m/s (54 km/h) passes a school crossing where the speed limit is 10 m/s (36 km/h). Just as the motorist passes the school-crossing sign, a police officer on a motorcycle stopped there starts in pursuit with constant acceleration 3.0 m/s^2. (a) How much time elapses before the officer passes the motorist? At that time, (b) what is the officer's speed and (c) how far has each vehicle traveled?

I am speed


(a)
Police officer: initially at rest, constant x-acceleration
Motorist: constant x-velocity
SCHOOL CROSSING
$a_{Px} = 3.0\ m/s^2$
$v_{M0x} = 15\ m/s$
O
x_P
x_M
x

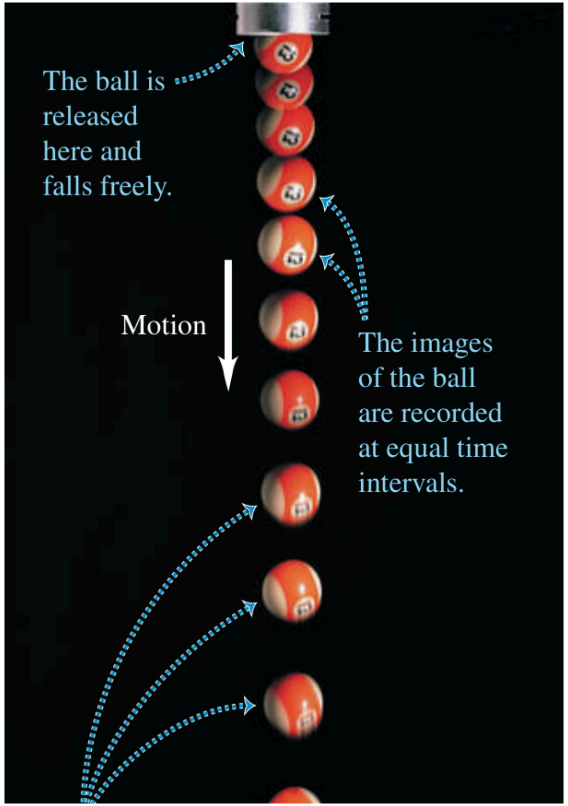

The police officer and motorist meet at the time t where their x-t graphs cross.
x (m)
160
120
80
40
Motorist
Officer
O
2
4
6
8
10
12
t (s)

Questions? 🤔

Freely falling objects 🪶

Free fall

- An object in **free-fall** experiences constant acceleration if air resistance is negligible (here only gravity affects the motion)
- On earth, all free-falling objects have an acceleration a_g due to gravity, which averages at $a_g = 9.8\text{m/s}^2$

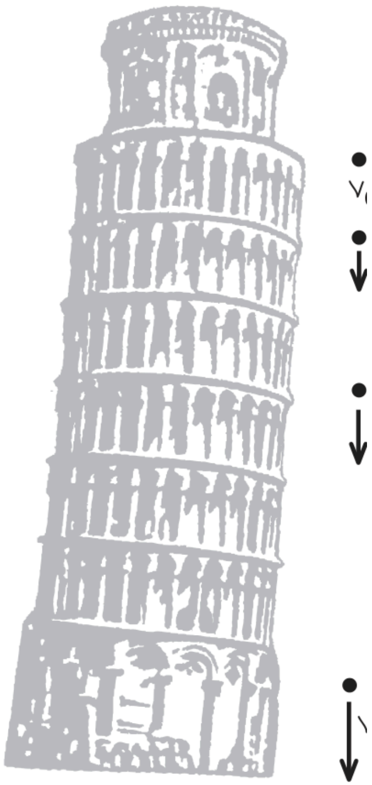


Free fall

- Acceleration a_g can be taken either as $+a_g$ or $-a_g$ depending on your choice of coordinate system. If you choose upward to be positive, $a = -a_g$ is negative, otherwise $a = a_g$. Former is the typical choice
- Since a is constant in free-fall, you can use above kinematic equations where either $a = \pm a_g$

A freely falling coin

Example. A one-peso coin is dropped from the Leaning Tower of Pisa and falls freely from rest. What are its position and velocity after 1.0 s, 2.0 s, and 3.0 s? Ignore air resistance.



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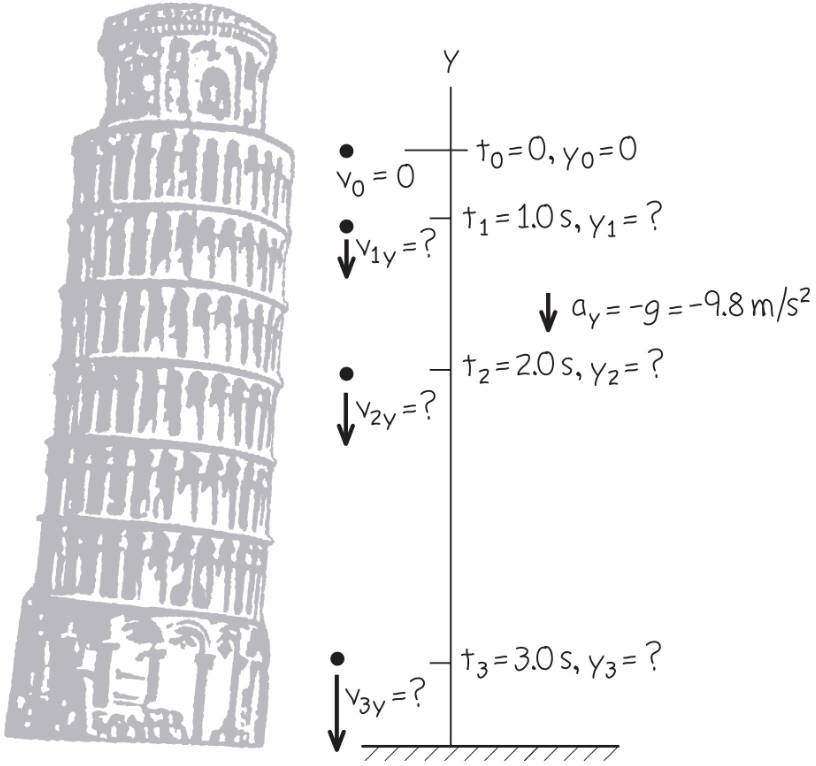

Questions? 🥱

Quiz time 🕐

I am speed: which v-t graph is correct? Why?