Physics 1501

Fall 2008

Mechanics, Thermodynamics, Waves, Fluids

Lecture 2: motion in a straight line I

Slide 2-1

Recap: The SI unit system

- Provides precise definitions of seven fundamental physical quantities
  - **Length**: the meter
  - **Time**: the second
  - **Mass**: the kilogram
  - **Electric current**: the ampere
  - **Temperature**: the kelvin
  - Amount of a substance: the mole
  - Luminous intensity: the candela
- Supplementary units describe angles
  - **Plane angle**: the radian
  - Solid angle: the steradian

Slide 2-2

Recap: Scientific notation

- The vast range of quantities that occur in physics are best expressed with ordinary-sized numbers multiplied by powers of 10:
  - $31416.5 = 3.14165 \times 10^4$
  - $0.002718 = 2.718 \times 10^{-3}$
- SI prefixes describe powers of 10:
  - Every three powers of 10 gets a different prefix.
  - Examples:
    - 3.0×10^9 W = 3.0 GW (3 gigawatts)
    - 1.6×10^{-8} m = 16 nm (16 nanometers)
    - 10^{12} kg = 1 Pg (1 petagram)

TABLE 1.1 SI Prefixes

Prefix	Symbol	Power
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
—	—	10^{0}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

Recap: Significant figures

- The answer to the last example in the preceding slide is 1.23 GJ—not 1234.8 MJ or 1.2348 GJ as your calculator would show.
  - That's because the given quantity, 343 kWh, has only three **significant figures.**
  - That means we know that the actual value is closer to 343 kWh than to 342 kWh or 344 kWh.
  - If we had been given 343.2 kWh, we would know that the value is closer to 343.2 kWh than to 343.1 kWh or 343.3 kWh.
    - In that case, the number given has four significant figures.
  - Significant figures tell how accurately we know the values of physical quantities.
    - Calculations can't increase that accuracy, so it's important to report the results of calculations with the correct number of significant figures.

Recap: Rules for significant figures

- In multiplication and division, the answer should have the same number of significant figures as the least accurate of the quantities entering the calculation.
  - Example: (3.1416 N)(2.1 m) = 6.6 N·m
    - Note the centered dot, normally used when units are multiplied (the kWh is an exception).
- In addition and subtraction, the answer should have the same number of digits to the right of the decimal point as the term in the sum or difference that has the smallest number of digits to the right of the decimal point.
  - Example: 3.2492 m – 3.241 = 0.008 m
    - Note the loss of accuracy, with the answer having only one significant figure.

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Recap: Estimation

- It's often sufficient to estimate the answer to a physical calculation, giving the result to within an order of magnitude or perhaps one significant figure.
- Estimation can provide substantial insight into a problem or physical situation.
- Example: What's the United States' yearly gasoline consumption?
  - There are about 300 million people in the U.S., so perhaps about 100 million cars (10^8 cars).
  - A typical car goes about 10,000 miles per year (10^4 miles).
  - A typical car gets about 20 miles per gallon.
  - So in a year, a typical car uses (10^4 miles)/(20 miles/gallon) = 500 gal.
  - So the United States' yearly gasoline consumption is about (500 gal/car)(10^8 cars) = 5×10^{10} gallons.
    - That's about 20×10^{10} L or 200 GL.

Slide 2-6

In this lecture:

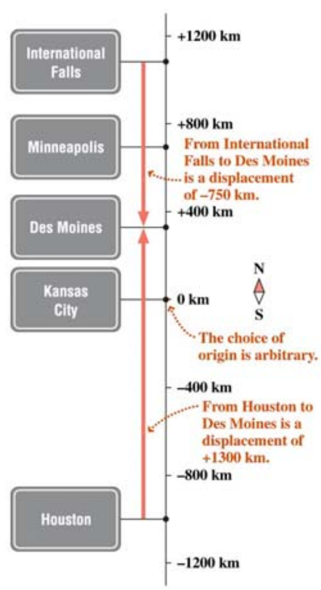
- The fundamental quantities that describe motion
  - Position
  - Velocity
  - Acceleration
- The difference between average and instantaneous quantities
  - The use of calculus to find instantaneous values
- How to solve problems involving constant acceleration in one dimension
  - Including the constant acceleration of gravity near Earth's surface

Position and displacement

- In one dimension, position can be described by a positive or negative number on a number line, also called a coordinate system.
  - Position zero, the origin of the coordinate system, is arbitrary and you're free to choose it wherever it's convenient.
- **Displacement** is change in position.
  - For motion along the x direction, displacement is designated Δx:

    $$\Delta x = x_2 - x_1$$

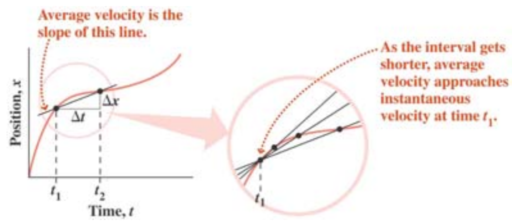
    where x_1 and x_2 are the initial and final positions, respectively.

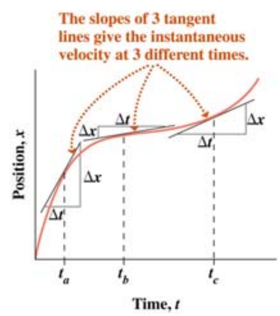


Velocity

- **Velocity** is the rate of change of position.
  - **Average velocity** over a time interval Δt is defined as the displacement divided by the time:
    $$\bar{v} = \frac{\Delta x}{\Delta t}$$
  - **Instantaneous velocity** is the limit of the average velocity as the time interval becomes arbitrarily short:
    $$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$
    - In calculus, this limiting procedure defines the **derivative** dx/dt.
  - **Speed** is the magnitude of velocity.

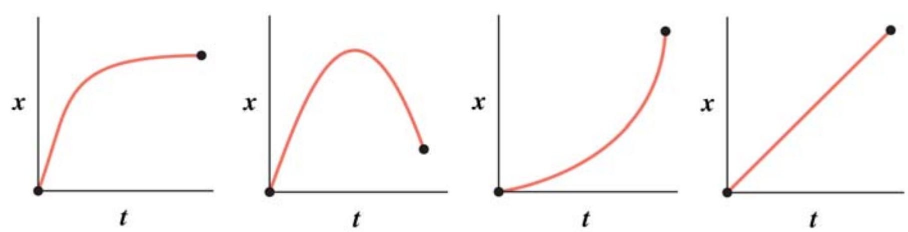
- Velocity is the slope of the position-versus-time curve.





question

- The figure shows position-versus-time graphs for four objects. Which starts slowly and then speeds up?



A. B. C. D.

Using calculus to find derivatives

- In calculus, the derivative gives the result of the limiting procedure.
  - Derivatives of powers are straightforward:

$$\frac{d\left(bt^n\right)}{dt} = bnt^{n-1}$$

  - Other common derivatives include the trig functions:

$$\frac{d\left(\sin bt\right)}{dt} = b\cos bt$$

$$\frac{d\left(\cos bt\right)}{dt} = -b\sin bt$$

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Acceleration

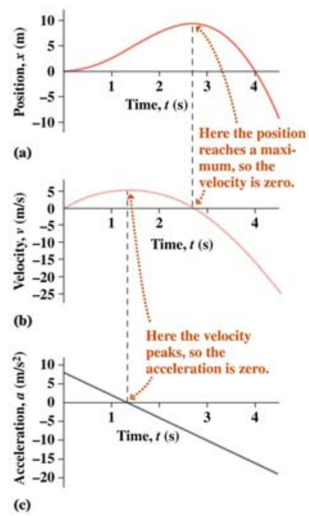
- **Acceleration** is the rate of change of velocity.
  - **Average velocity** over a time interval Δt is defined as the change in velocity divided by the time:

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

  - **Instantaneous acceleration** is the limit of the average acceleration as the time interval becomes arbitrarily short:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

- Acceleration is the slope of the velocity-versus-time curve.



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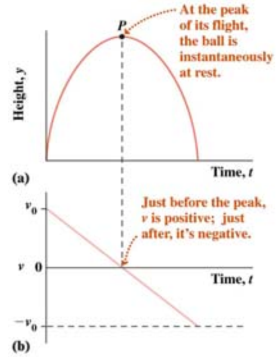
Position, velocity, and acceleration

- Individual values of position, velocity, and acceleration aren't related.
  - Instead, velocity depends on the *rate of change* of position.
  - Acceleration depends on the *rate of change* of velocity.
  - An object can be at position $x = 0$ and still be *moving*.
  - An object can have zero velocity and still be *accelerating*.

At the peak of its trajectory, a ball has zero velocity, but it's still accelerating.



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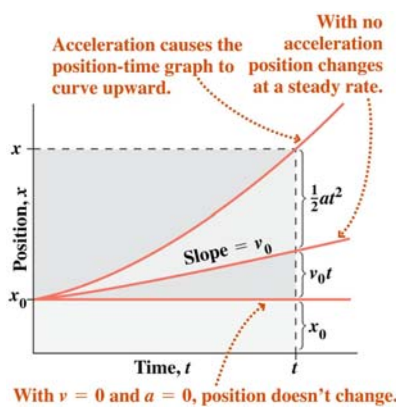
Constant acceleration

- When acceleration is constant, then position, velocity, acceleration, and time are related by

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

where x_0 and v_0 are initial values at time $t = 0$, and x and v are the values at an arbitrary time t.

- With constant acceleration
  - Velocity is a linear function of time
  - Position is a quadratic function of time



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question

- A speeding motorist zooms past a stationary police car, which then heads after the speeder. The police car starts with zero velocity and is going at twice the car's velocity when it catches up to the car. So at some intermediate instant the police car must be going at the same velocity as the speeding car. When is that instant?

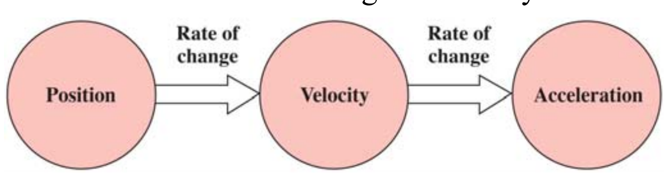
A. Closer to the time when the police car starts chasing

B. Closer to the time when the police car catches the speeder

C. Halfway between the times when the two cars coincide

Summary

- Position, velocity, and acceleration are the fundamental quantities describing motion.
  - Velocity is the rate of change of position.
  - Acceleration is the rate of change of velocity.



- When acceleration is constant, simple equations relate position, velocity, acceleration, and time.
  - An important case is the acceleration due to gravity near Earth's surface.
  - The magnitude of the gravitational acceleration is $g = 9.8\ \text{m/s}^2$.

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