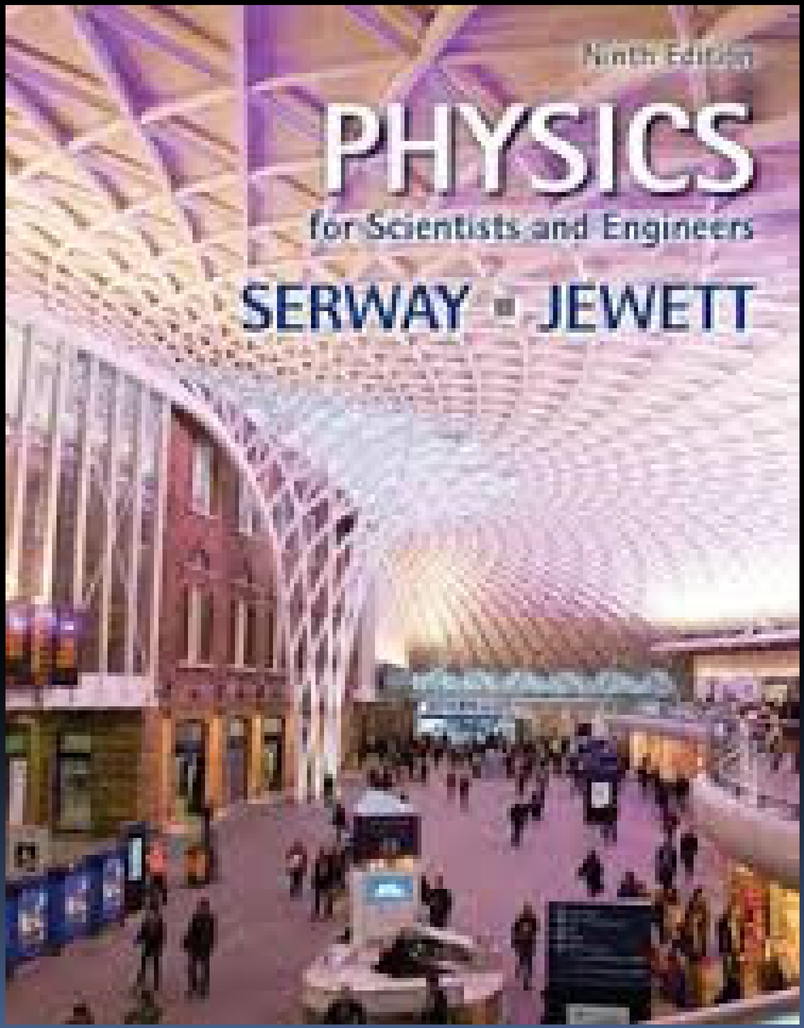
Nitipat Pholchai (NPC)
Physics I (EPH) 2014-I

LECTURE 0: PHYSICS INTRO INTUITION, MODELING AND PROBLEM-SOLVING

General info

- Instructor: Nitipat Pholchai (นิธิพัฒน์ พลชัย: NPC)
  - Office hours: Thu 1-4pm or by appointment
  - Email: ong.pholchai@gmail.com
  - Course Website: http://landos.stri.kmutnb.ac.th/main/people/nitipat-pholchai/npc-physics-i-2014-i-index
- Attendance rules
- Text:
  - Serway, Jewett "Physics for Scientists and Engineers"
  - ผศ. ดร. วุฒิพันธุ์ ปรัชญพฤกษ์, "ฟิสิกส์ (กลศาสตร์)", โครงการตำราวิทยาศาสตร์ สอวน.
- Exam
  - Midterm : 12-17 Oct
  - Final : 105 Dec

Recommended textbook



Attendance rules

- FULL SCORE (10 pts.) = arrive within first 15 mins and stay focused/present throughout lecture period
- LATE (5 pts) = more than 15 mins late or not fully present during lecture period
- ABSENCE (0 pts)
  - 2x LATE = 1 absence
  - Not allowed to take final exam if total score < 120 pts, which means you are allowed maximum 3 absence

Physics I: Syllabus

- Part I: Force and Motion
  1. Concepts of Motion and Math Background
  2. Motion in 1D:
  3. Vectors and Motion in 2D
  4. Forces (Newton's Law of Motion)
- Part II : Energy and Momentum
- Part III : Motion of rigid body
- Part IV: Fluids
- Part V: Thermodynamics

Outline

1. Physics: what and why?
2. Dealing with quantities

Outline

1. Physics: what and why?
2. Dealing with quantities

Why study Physics?

- Write 3-5 things you want to get out of this course? Explain why they matter to YOU.

How to do well in Physics I

- Keep asking yourself…why should we want to know this?
  - What people use this for? As scientists, engineers, the prime minister, football player, a citizen
  - Where is the frontier of knowledge?
  - What are the useful skills (if not the knowledge)?
    - Intuition, problem-solving, analytical thinking?
- What is missing, not covered in this class?

(but still relevant or interesting)

How to do well in Physics I (ii)

- Be an ACTIVE student
  - Review materials before each lecture
  - Anticipate/ask lots of questions (even if you are not sure how to answer them)
- SOLVE A LOT OF PROBLEMS!!!

What is Physics?

- As a Fundamental Science
  - Concerned with the fundamental principles of the Universe
  - Foundation of other physical sciences
    - Apparatus, tools
  - Has simplicity of fundamental concepts
    - Methods of abstraction

- But also highly developed and applied!!!

Hubble Space Telescope

Spacecraft orbital dynamics

Rigid body dynamics

Continuum model of mirror

Major body of knowledge

Classical Mechanics:

- mechanical engineering, automotive/aeronautic/robotics, mechanics of materials, fluid dynamics, combustion, physiology/biomechanics, geophysics

Relativity:

- astrophysics, GPS, meteorology, space, cosmology, metrology

Thermodynamics and statistical mechanics:

- chemical engineering, material, machine, biophysics, financial mathematics, information theory

Electromagnetics:

- electrical/electronics engineering, material, energy science, **optics**/microwave, biophysics, physiology

Quantum theory:

- materials, microelectronics etc., nuclear science

Objectives of Physics

- To find the limited number of **fundamental laws** that govern **natural phenomena**
  - **what and why?**
- To use these laws to develop theories that can **predict** the results of future experiments
- Express the laws in the **analytical language** of mathematics
  - Mathematics provides the bridge between theory and experiment
  - Tenets of science and engineering: Validation/Verification → Control)

Theory and Experiments

- The basic rule is that they should complement each other

→When a discrepancy occurs, theory may be modified or new theories formulated.

→But really why do we do experiments?

- A theory may apply to limited conditions.
  - Example: Newtonian Mechanics is confined to objects traveling slowly with respect to the speed of light.
  - **In fact, physical theories are "limiting cases" of one another.**
- Try to develop a more **general (powerful) theory**
  - **But…"reductionism" vs "emergent phenomena"**
  - **"Formulation" matters!!**

Special Relativity (SR)

- Correctly describes motion of objects moving near the speed of light or at astronomical distance
- Modifies the traditional concepts of space, time, and energy
- Shows the speed of light is the upper limit for the speed of an object
- = maximum speed of information is “finite”
- Shows mass and energy are related

Quantum Mechanics (QM)

- Formulated to describe physical phenomena at the atomic level (i.e. small momentum = isolated small mass or slow object)
- Led to the development of many practical devices

e.g. electron microscopy (matter wave optics)

all electronic devices: transistor, digital camera, your smartphones, lasers, LED, display technology, solar cells etc.

- Both QM and SR provide limiting cases to classical mechanics through "**correspondence principle**"

Outline

1. Physics: what and why?
2. **Dealing with quantities**

Quantities and Measurements (how to be “number smart”)

- Units, **Dimensional Analysis**
- **Order of magnitude** (scales)
  - Scientific notations
  - Use it to check if result is reasonable, also for unit conversion
- **Significant figures** and rounding

Units

"Your units are wrong!", cried the teacher
Your church weighs 6 joules--what a feature!
And the people inside,
are 4 hours wide
And 8 gauss away from the preacher!

David Morin

Fundamental Quantities and Their Units

Quantity	SI Unit
Length [L]	meter
Mass [M]	kilogram
Time [T]	second
Temperature	Kelvin
Electric Current	Ampere
Luminous Intensity	Candela
Amount of Substance	mole

Prefixes, cont.

TABLE 1.4 *Prefixes for Powers of Ten*

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

Dimensions and Units

- Each dimension can have many actual units.
- Table 1.5 for the dimensions and units of some derived quantities

TABLE 1.5 *Dimensions and Units of Four Derived Quantities*

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

Dimensional Analysis

1. Technique to check the correctness of an equation or to assist in deriving an equation
2. Limitation is that it cannot give numerical factors

Example 1

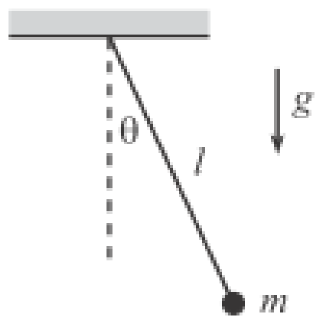


Figure 1.1

Example 1 (Pendulum): A mass m hangs from a massless string of length ℓ (see Fig. 1.1) and swings back and forth in the plane of the paper. The acceleration due to gravity is g. What can we say about the frequency of oscillations?

Uncertainty in Measurements

- There is uncertainty in every measurement – this uncertainty carries over through the calculations. **(propagation of errors)**
  - May be due to the apparatus, the experimenter, and/or the number of measurements made
  - Need a technique to account for this uncertainty
- We will use rules for **significant figures** to approximate the uncertainty in results of calculations.

Significant Figures

- A significant figure is one that is reliably known. (the amount of information in a number)
- Zeros may or may not be significant.
  - Those used to position the decimal point are not significant.
  - To remove ambiguity, use **scientific notation**.
- In a measurement, the significant figures include the first estimated digit.

Significant Figures, examples

- 0.0075 m has 2 significant figures
  - The leading zeros are placeholders only.
  - Write the value in scientific notation to show more clearly:

    7.5×10^{-3} m for 2 significant figures
- 10.0 m has 3 significant figures
  - The decimal point gives information about the reliability of the measurement.
- 1500 m is ambiguous
  - Use 1.5×10^{3} m for 2 significant figures
  - Use 1.50×10^{3} m for 3 significant figures
  - Use 1.500×10^{3} m for 4 significant figures

Operations with Significant Figures – Multiplying or Dividing

- When multiplying or dividing several quantities, the number of significant figures in the final answer is the same as the number of significant figures in the quantity having the smallest number of significant figures.
- Example: 25.57 m x 2.45 m = 62.6 m^2
  - The 2.45 m limits your result to 3 significant figures.

Operations with Significant Figures – Adding or Subtracting

- When adding or subtracting, the number of decimal places in the result should equal the smallest number of decimal places in any term in the sum or difference.
- Example: 135 cm + 3.25 cm = 138 cm
  - The 135 cm limits your answer to the units decimal value.

Operations With Significant Figures – Summary

- The rule for addition and subtraction are different than the rule for multiplication and division.
- For adding and subtracting, the ***number of decimal places*** is the important consideration.
- For multiplying and dividing, the ***number of significant figures*** is the important consideration.

Example 2

1. A carpet is to be installed in a rectangular room of length measured to be 12.71 m and of width measured to be 3.46m. Find the area of the room. (hint: calculator gives 43.9766 m^2)

Lecture 1

Motion in One Dimension

Outline

1. Kinematics vs Dynamics
   – Types of motion, Space and time, Coordinates
   – Particle model, motion diagram, table and graphical method (experiment)
   – mathematical representation (differential calculus)
2. Modeling motion: quantities
   – Vectors vs scalars
   – Position, displacement/distance, velocity/speed
   – Averaged vs instantaneous
   – Acceleration
3. 1D Uniform acceleration (kinematic equations)

Why studying motion

- – Develop intuition about "**acceleration**"
- – Mathematical tools: calculus, review of algebra
- Examples of 1D motion of particle under constant acceleration
  - – Accelerating car at constant rate
  - – Dropped object in the absence of air
  - – Object moving under constant net force
  - – A charged particle in uniform electric field e.g. DNA in a microarray

> High jump Video

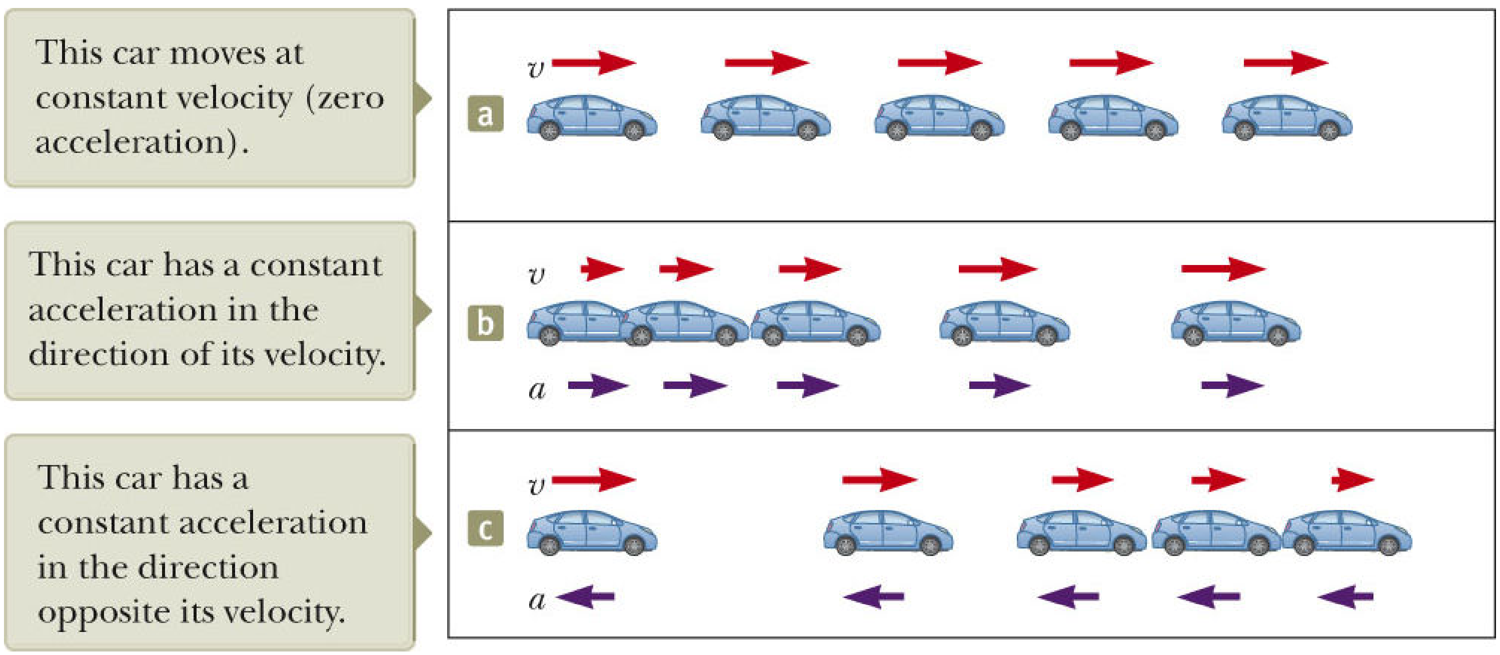
Kinematics

- Describes motion while ignoring the external agents that might have caused or modified the motion
- Motion represents a continual change in an object's position.

Kinematics = how, Dynamics = why

Intuition: Motion Diagrams

- A **motion diagram** can be formed by imagining the stroboscope photograph/snapshots of a moving object.
- Red arrows represent velocity.
- Purple arrows represent acceleration.



Types of Motion

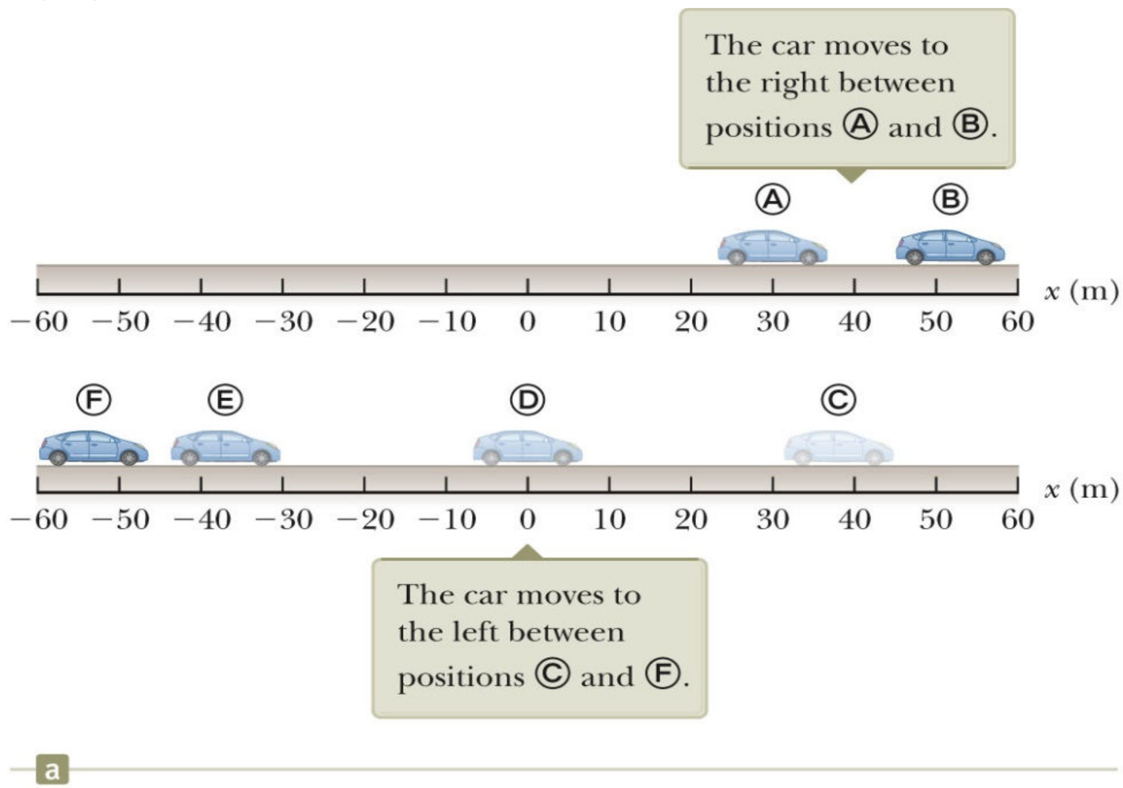
- Translational
  - An example is a car traveling on a highway.
- Rotational
  - An example is the Earth's spin on its axis.
- Vibrational
  - An example is the back-and-forth movement of a pendulum. (extremely ubiquitous in nature)

Particle Model

- We will use the particle model.
  - A particle is a point-like object; has mass but infinitesimal size

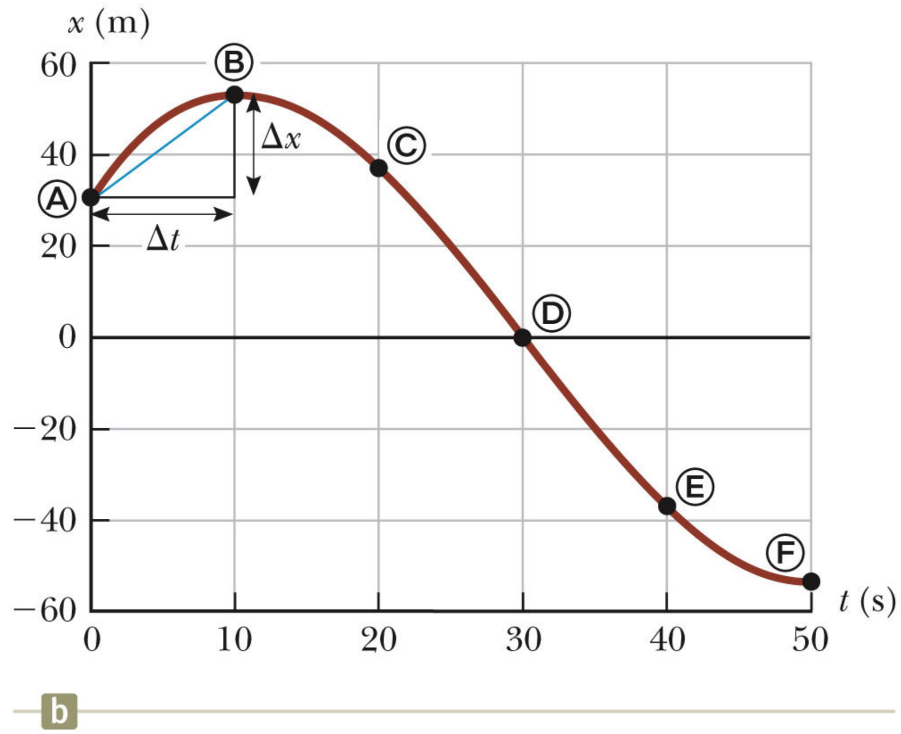
Position

- The object's position is its location with respect to a chosen **reference point.**
  - Consider the point to be the **origin of a coordinate system**.
- Only interested in the car's translational motion, so model as a particle



Position-Time Graph

- The position-time graph shows the motion of the particle (car).
- The smooth curve is a guess as to what happened between the data points.



Data Table

- The table gives the actual data collected during the motion of the object (car).
- Positive is defined as being to the right.

TABLE 2.1

Position of the Car at Various Times

Position	t (s)	x (m)
Ⓐ	0	30
Ⓑ	10	52
Ⓒ	20	38
Ⓓ	30	0
Ⓔ	40	−37
Ⓕ	50	−53

Alternative Representations

- Using alternative representations is often an excellent strategy for understanding a problem.
  - For example, the car problem used multiple representations.
    - Pictorial representation
    - Graphical representation
    - Tabular representation
- Goal is often a mathematical representation

Displacement

- Displacement is defined as the change in position during some time interval.
  - Represented as Δx

$$\Delta x \equiv x_f - x_i$$

  - SI units are meters (m)
  - Δx can be positive or negative
- Different than distance
  - Distance is the length of a path followed by a particle.

Distance vs. Displacement – An Example

- Assume a player moves from one end of the court to the other and back.
- Distance is twice the length of the court
  - Distance is always positive
- Displacement is zero
  - $\Delta x = x_f - x_i = 0$ since $x_f = x_i$

Vectors and Scalars

- Vector quantities need both magnitude (size or numerical value) and direction to completely describe them.
  - Will use + and – signs to indicate vector directions in this chapter (1D)
- Scalar quantities are completely described by magnitude only.

Displacement	distance
Velocity	speed

Average Velocity

- The **average velocity** is rate at which the displacement occurs.

$$v_{x,avg} \equiv \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$$

  – The x indicates motion along the x-axis.

- The dimensions are length / time [L/T]
- The SI units are m/s
- Is also the slope of the line in the position – time graph

Average Speed

- **Speed** is a scalar quantity.
  - Has the same units as velocity
  - Defined as total distance / total time:

$$v_{avg} \equiv \frac{d}{t}$$

- The speed has no direction and is always expressed as a positive number.
- Neither average velocity nor average speed gives details about the trip described.

Average Speed and Average Velocity

Is average speed = magnitude of the average velocity?

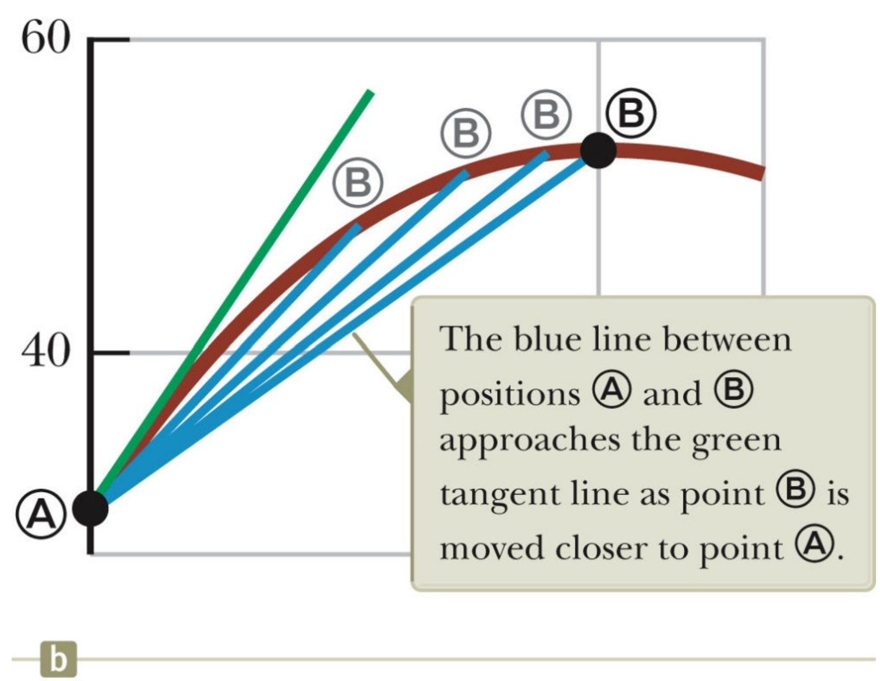
- a runner ends at her starting point.

Instantaneous Velocity

- The limit of the average velocity as the time interval becomes infinitesimally short, or as the time interval approaches zero.
- The instantaneous velocity indicates what is happening at every point of time.

Instantaneous Velocity, graph

- The instantaneous velocity is the slope of the line tangent to the *x* vs. *t* curve.
  - This would be the green line.
- The light blue lines show that as Δt gets smaller, they approach the green line.



A Note About Slopes

- The slope of a graph of physical data represents the ratio of change in the quantity represented on the vertical axis to the change in the quantity represented by the horizontal axis.
- The slope has units
  - Unless both axes have the same units

Instantaneous Velocity, equations

- The general equation for instantaneous velocity is:

$$v_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

- The instantaneous velocity can be positive, negative, or zero.

Instantaneous Speed

- The instantaneous speed is the magnitude of the instantaneous velocity.
- The instantaneous speed has no direction associated with it.

Vocabulary Note

- “Velocity” and “speed” will generally indicate *instantaneous* values.
- *Average* will be used when the average velocity or average speed is indicated.

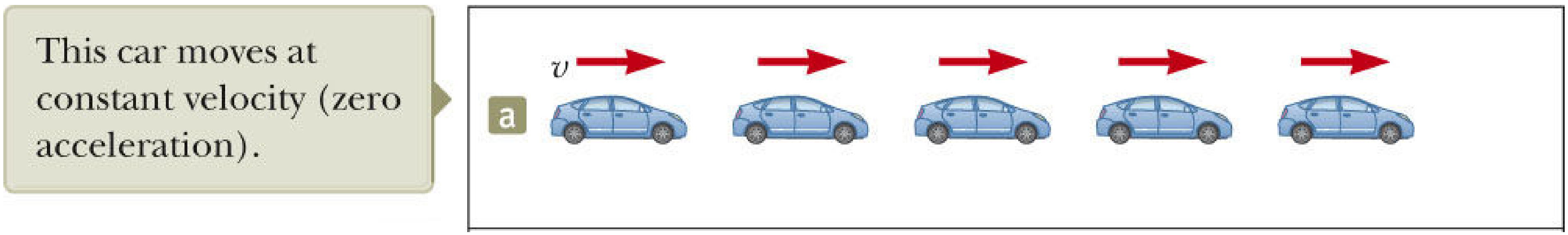
Analysis Models

- Analysis models are an important technique in the solution to problems.
- An analysis model is a description of:
  - The behavior of some physical entity, or
  - The interaction between the entity and the environment.
- Try to identify the fundamental details of the problem and attempt to recognize which of the types of problems you have already solved could be used as a model for the new problem.

Analysis Models, cont

- Based on four *simplification models*
  - Particle model
  - System model
  - Rigid object
  - Wave
- Problem approach
  - Identify the analysis model that is appropriate for the problem.
  - The model tells you which equation to use for the mathematical representation.

Model: A Particle Under Constant Velocity



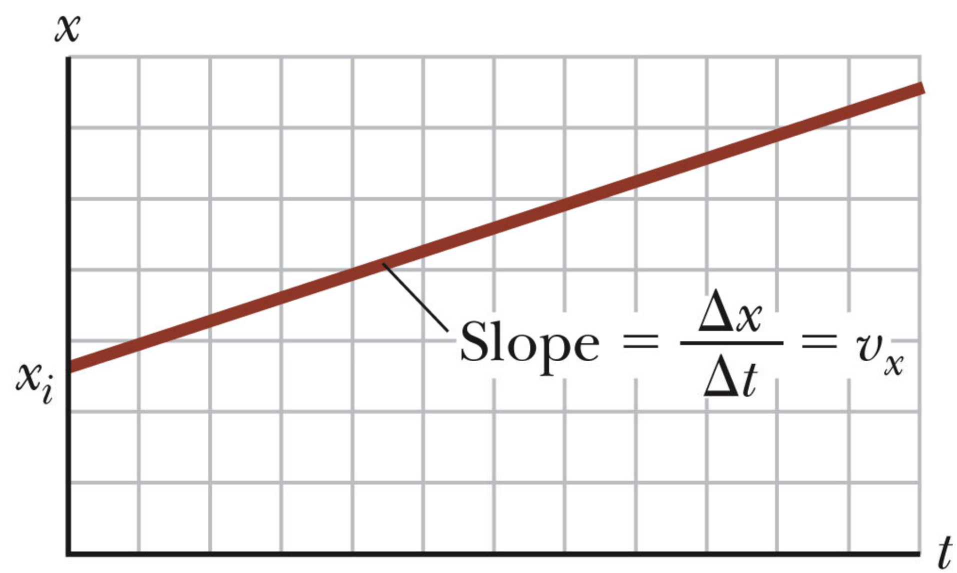
- Constant velocity indicates the instantaneous velocity at any instant during a time interval is the same as the average velocity during that time interval.
  - $v_x = v_{x,\,avg}$
  - The mathematical representation of this situation is the equation.

$$v_x = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t} \quad or \quad x_f = x_i + v_x \Delta t$$

  - Common practice is to let $t_i = 0$ and the equation becomes: $x_f = x_i + v_x t$ (for constant v_x)

Particle Under Constant Velocity, Graph

- The graph represents the motion of a particle under constant velocity.
- The slope of the graph is the value of the constant velocity.
- The y-intercept is x_i.



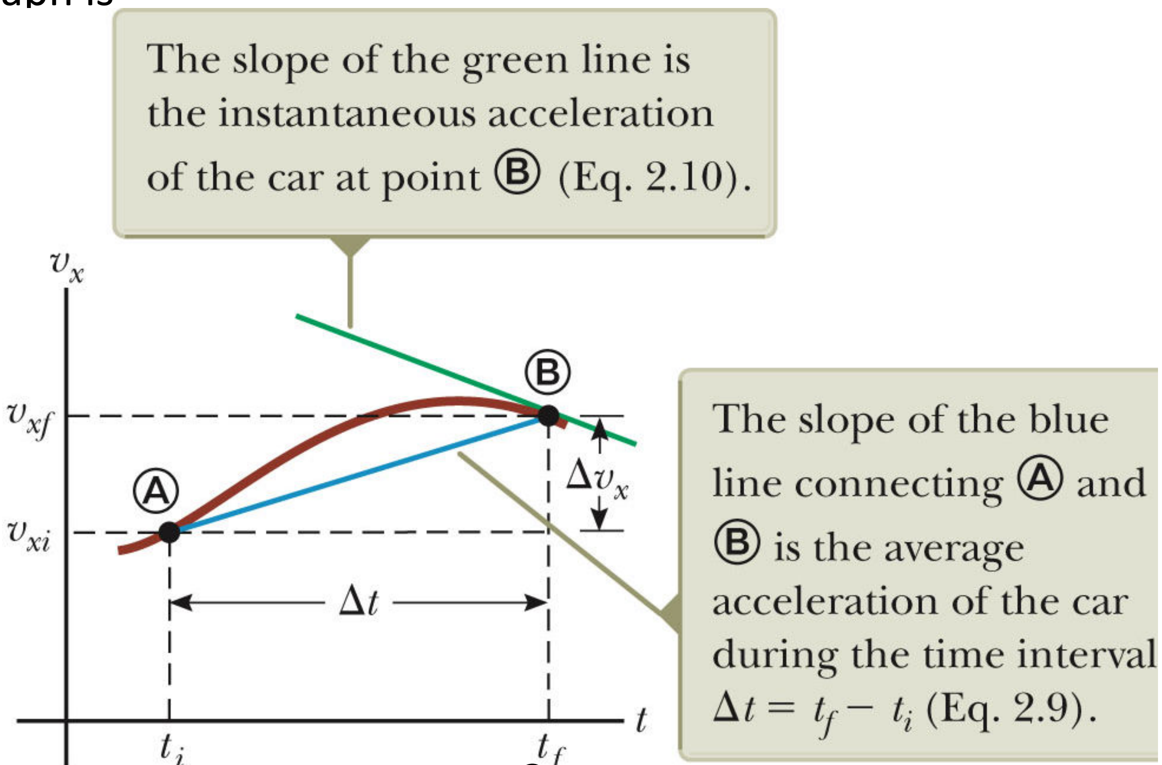
Model: A Particle Under Constant Speed

- A particle under constant velocity moves with a constant speed along a straight line.
- A particle can also move with a constant speed along a curved path.
- This can be represented with a model of a **particle under constant speed.**
- The primary equation is the same as for average speed, with the average speed replaced by the constant speed.

$$v = \frac{d}{\Delta t}$$

(Instantaneous) Acceleration

- The slope of the velocity-time graph is the acceleration.
- The green line represents the instantaneous acceleration.
- The blue line is the average acceleration.

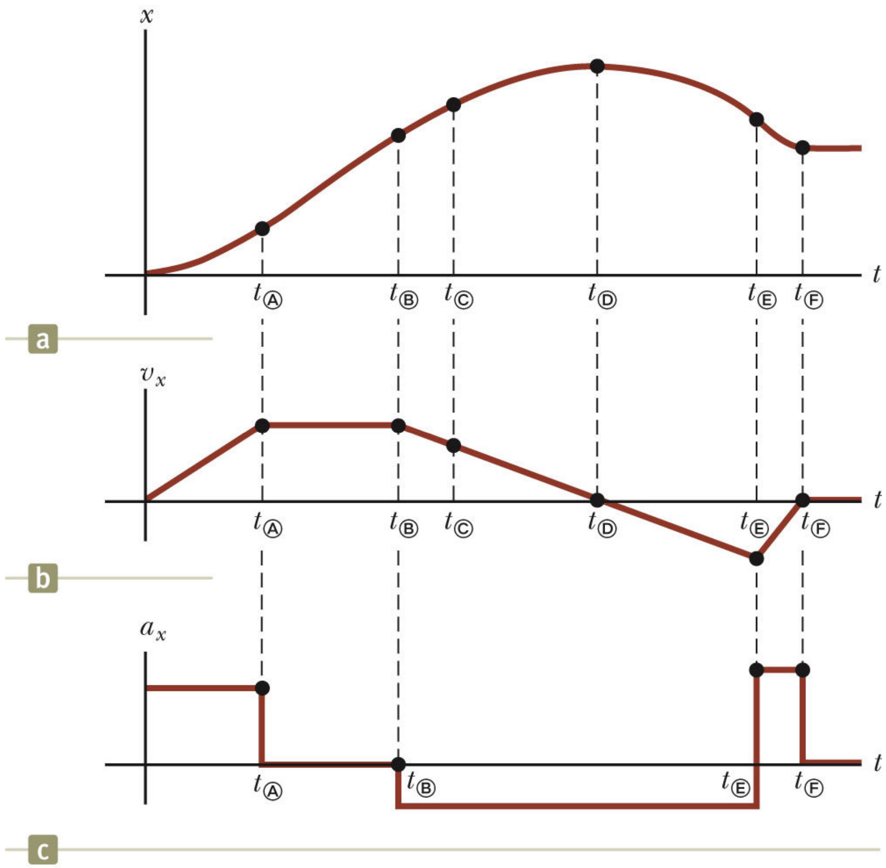


$$a_x = \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt} = \frac{d^2x}{dt^2}$$

Summary: graphical comparison

- Given the displacement-time graph (a)
- The velocity-time graph is found by measuring the slope of the position-time graph at every instant.
- The acceleration-time graph is found by measuring the slope of the velocity-time graph at every instant.

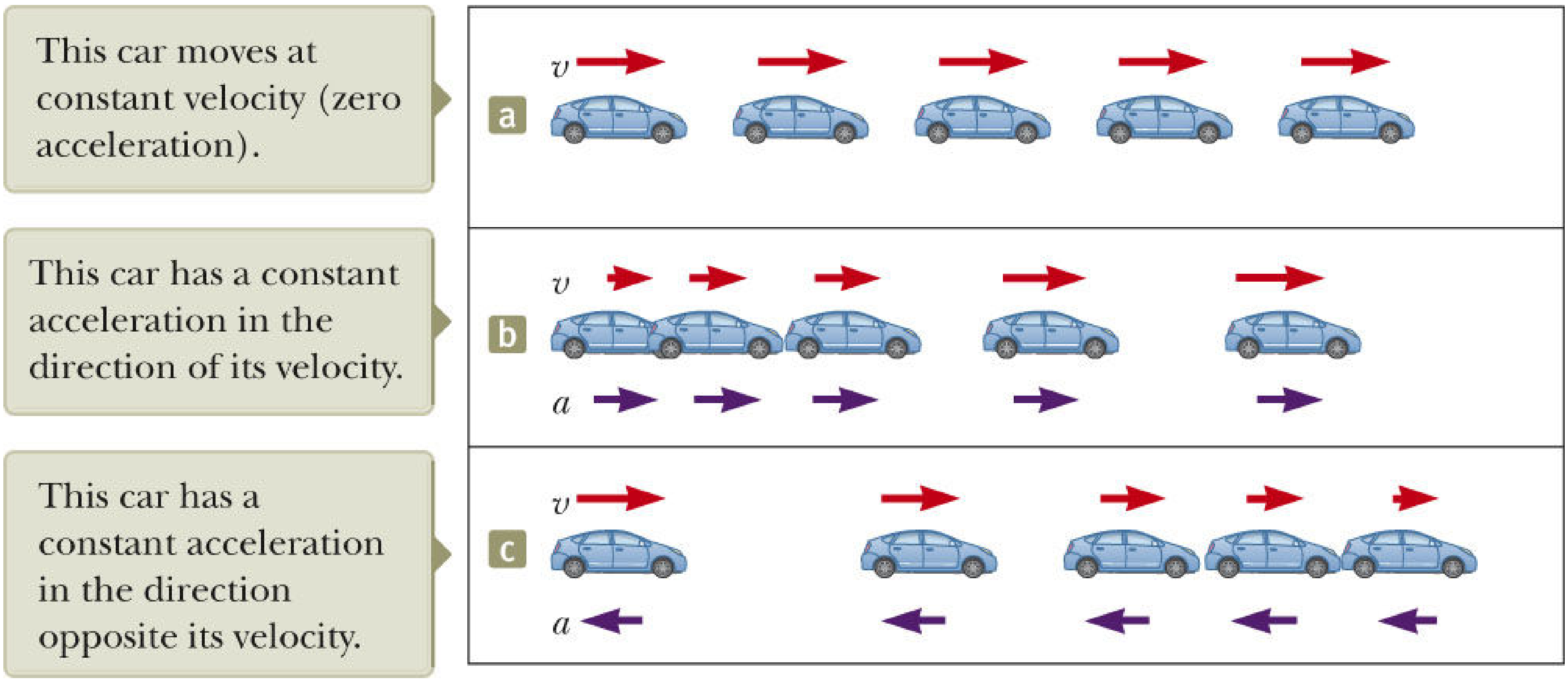
- How to reverse the procedure i.e. suppose we know acceleration at any given time?



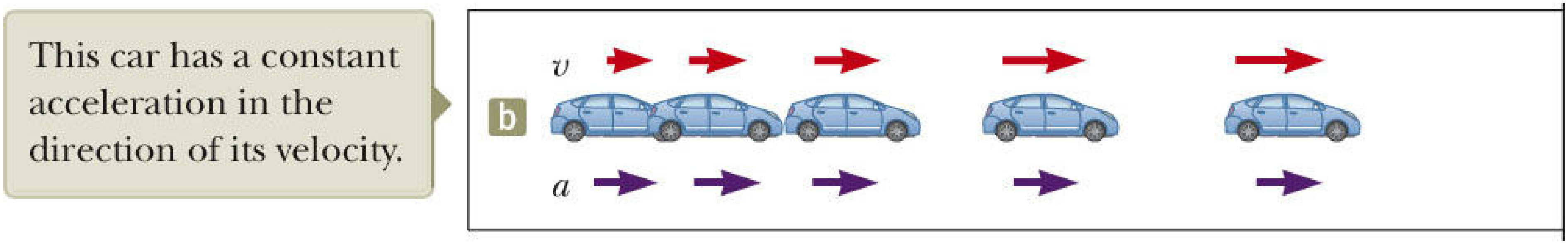
Acceleration and Force

- The acceleration of an object is related to the total force exerted on the object.
  - The force is proportional to the acceleration, $F_x \propto a_x$.
  - Assume the velocity and acceleration are in the same direction.
    - The force is in the same direction as the velocity and the object speeds up.
  - Assume the velocity and acceleration are in opposite directions.
    - The force is in the opposite direction as the velocity and the object slows down.

Recap

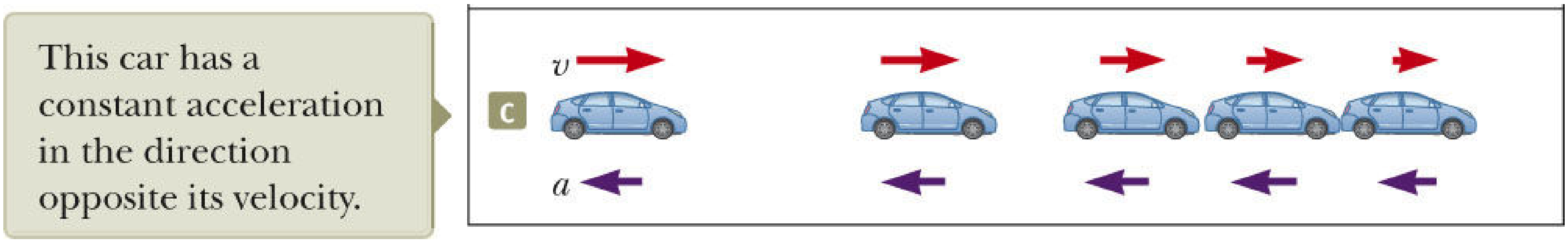

This car moves at constant velocity (zero acceleration).
This car has a constant acceleration in the direction of its velocity.
This car has a constant acceleration in the direction opposite its velocity.
a
b
c
v
a

Acceleration and Velocity, 3



- Images become farther apart as time increases.
- Velocity and acceleration are in the same direction.
- Acceleration is uniform (violet arrows maintain the same length).
- Velocity is increasing (red arrows are getting longer).
- This shows positive acceleration and positive velocity.

Acceleration and Velocity, 4



- Images become closer together as time increases.
- Acceleration and velocity are in opposite directions.
- Acceleration is uniform (violet arrows maintain the same length).
- Velocity is decreasing (red arrows are getting shorter).
- Positive velocity and negative acceleration.

Kinematic Equations

- The kinematic equations can be used with any particle under uniform acceleration.
- The kinematic equations may be used to solve any problem involving one-dimensional motion with a constant acceleration.
- You may need to use two of the equations to solve one problem.
- Many times there is more than one way to solve a problem.

Kinematic Equations, 1

- For constant a_x,

$$v_{xf} = v_{xi} + a_x t$$

- Can determine an object's velocity at any time t when we know its initial velocity and its acceleration
  - Assumes $t_i = 0$ and $t_f = t$
- Does not give any information about displacement

Kinematic Equations, 2

- For constant acceleration,

$$v_{x,avg} = \frac{v_{xi} + v_{xf}}{2}$$

- The average velocity can be expressed as the arithmetic mean of the initial and final velocities.
  - This applies only in situations where the acceleration is constant.

Kinematic Equations, 3

- For constant acceleration,

$$x_f = x_i + v_{x,avg}\,t = x_i + \frac{1}{2}\left(v_{xi} + v_{fx}\right)t$$

- This gives you the position of the particle in terms of time and velocities.
- Doesn’t give you the acceleration

Kinematic Equations, 4

- For constant acceleration,

$$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$$

- Gives final position in terms of velocity and acceleration
- Doesn't tell you about final velocity

Kinematic Equations, 5

- For constant *a*,

$$v_{xf}^2 = v_{xi}^2 + 2a_x\left(x_f - x_i\right)$$

- Gives final velocity in terms of acceleration and displacement
- Does not give any information about the time

Kinematic Equations – summary

TABLE 2.2 *Kinematic Equations for Motion of a Particle Under Constant Acceleration*

Equation Number	Equation	Information Given by Equation
2.13	$v_{xf} = v_{xi} + a_x t$	Velocity as a function of time
2.15	$x_f = x_i + \frac{1}{2}(v_{xi} + v_{xf})t$	Position as a function of velocity and time
2.16	$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$	Position as a function of time
2.17	$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$	Velocity as a function of position

Note: Motion is along the x axis.

Describe each equation in words!

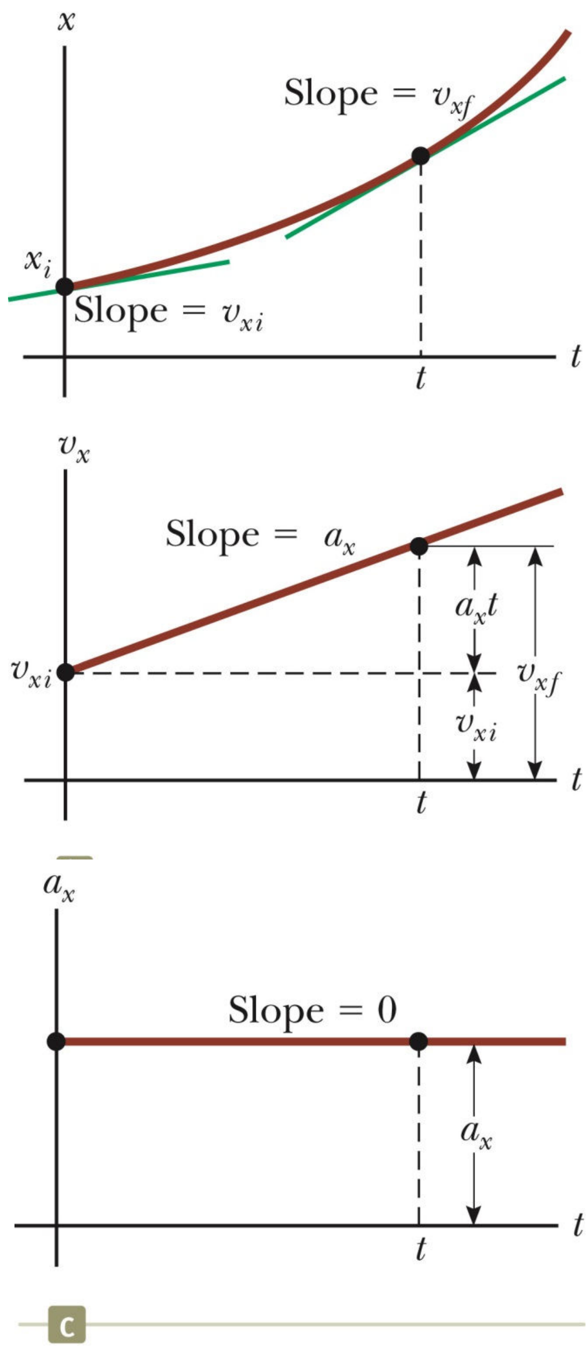
Hint: Use graph

How to use these equations:

Limiting case when a = 0

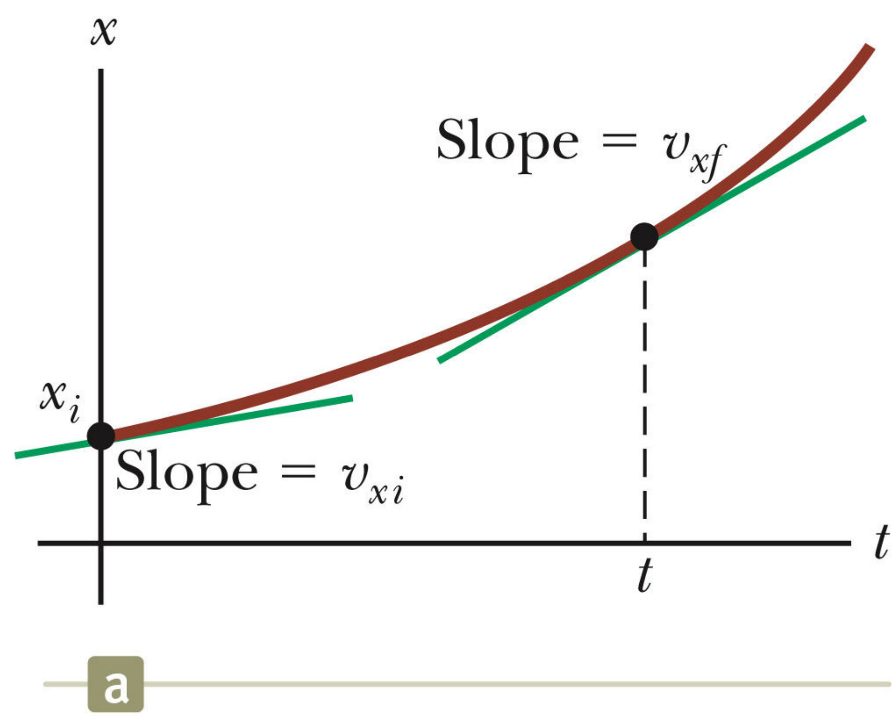
- When the acceleration is zero,
  - $v_{xf} = v_{xi} = v_x$
  - $x_f = x_i + v_x\,t$
- The constant acceleration model reduces to the constant velocity model.

Constant acceleration- Graphical



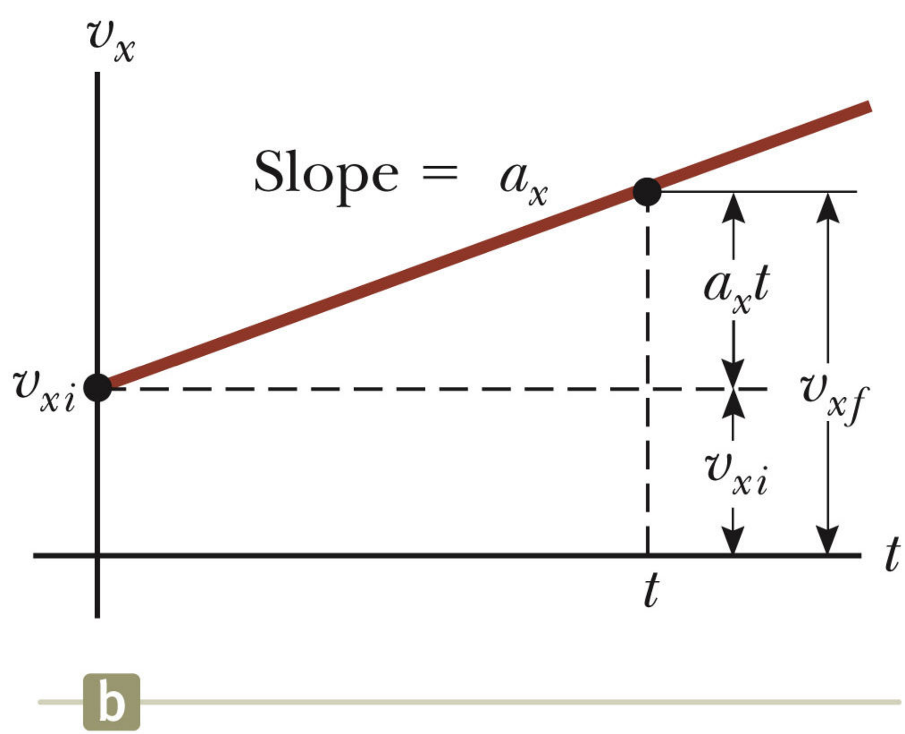
Graphical Look at Motion: Displacement – Time curve

- The slope of the curve is the velocity.
- The curved line indicates the velocity is changing.
  - Therefore, there is an acceleration.



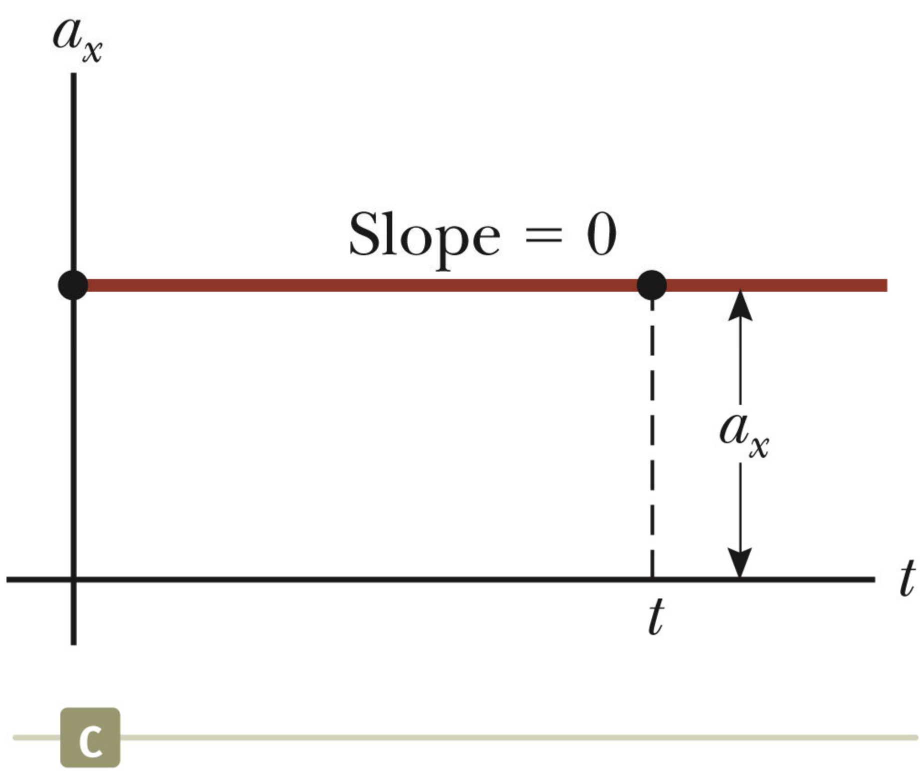
Graphical Look at Motion: Velocity – Time curve

- The slope gives the acceleration.
- The straight line indicates a constant acceleration.



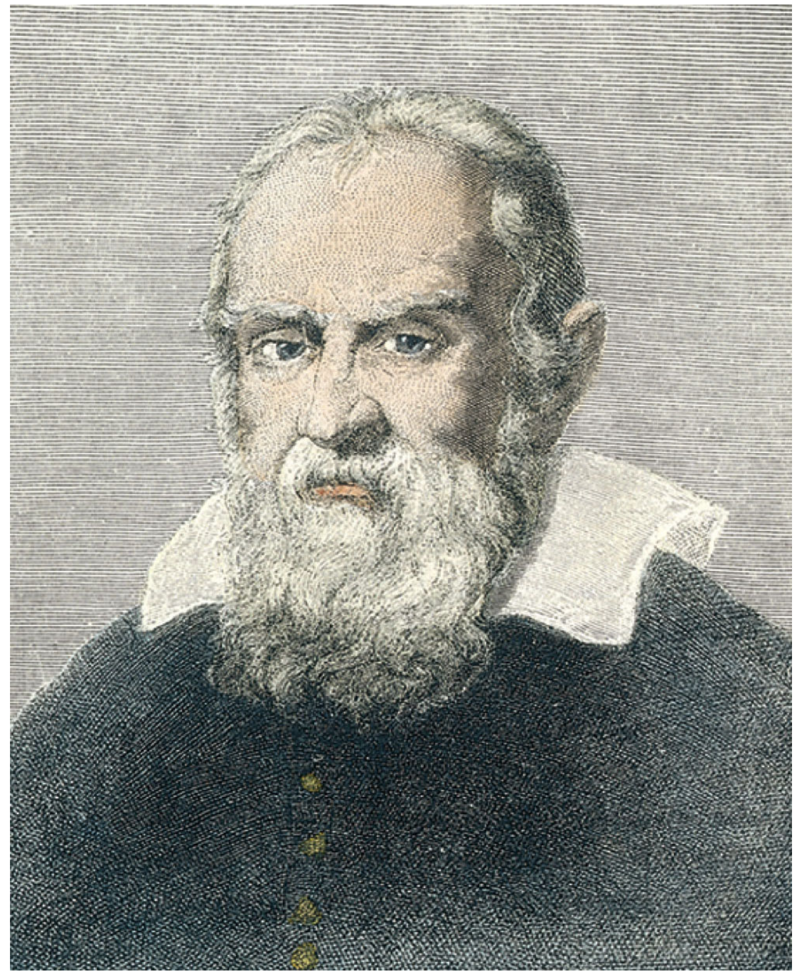
Graphical Look at Motion: Acceleration – Time curve

- The zero slope indicates a constant acceleration.



Galileo Galilei

- 1564 – 1642
- Italian physicist and astronomer
- Formulated laws of motion for objects in free fall
- Supported heliocentric universe



Freely Falling Objects

- A ***freely falling object*** is any object moving freely under the influence of gravity alone.
- It does not depend upon the initial motion of the object.
  - Dropped – released from rest
  - Thrown downward
  - Thrown upward

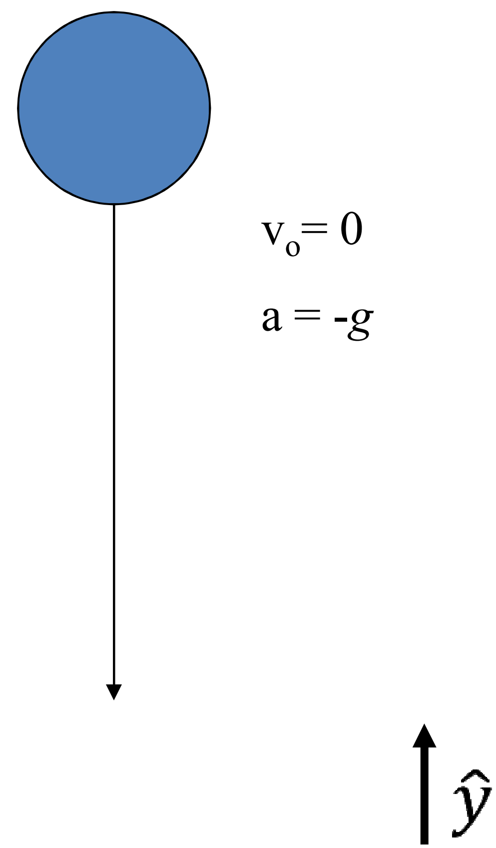
Acceleration of Freely Falling Object

- The acceleration of an object in free fall is directed downward, regardless of the initial motion.
- The magnitude of free fall acceleration is $g = 9.80$ m/s^2.
  - g decreases with increasing altitude
  - g varies with latitude
  - 9.80 m/s^2 is the average at the Earth's surface
  - The italicized g will be used for the acceleration due to gravity.
    - Not to be confused with g for grams

Free Fall – An Object Dropped

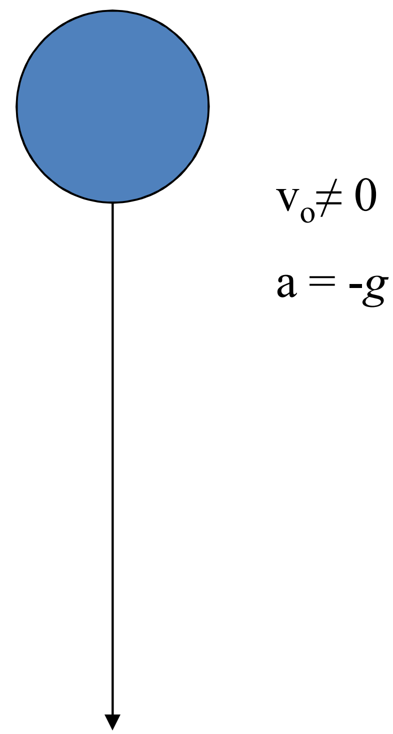
- Initial velocity is zero
- Let up be positive $+\hat{y}$ direction
- Use the kinematic equations
- Acceleration is

  $a_y = -g = -9.80 \text{ m/s}^2$



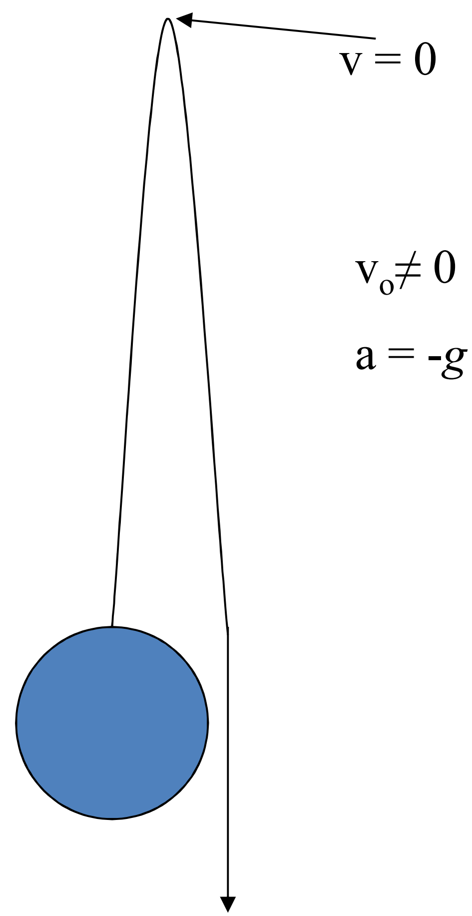
Free Fall – An Object Thrown Downward

- $a_y = -g = -9.80 \text{ m/s}^2$
- Initial velocity $\neq 0$
  - With upward being positive, initial velocity will be negative.



Free Fall – Object Thrown Upward

- Initial velocity is upward, so positive
- The instantaneous velocity at the maximum height is zero.
- $a_y = -g = -9.80\ m/s^2$ everywhere in the motion

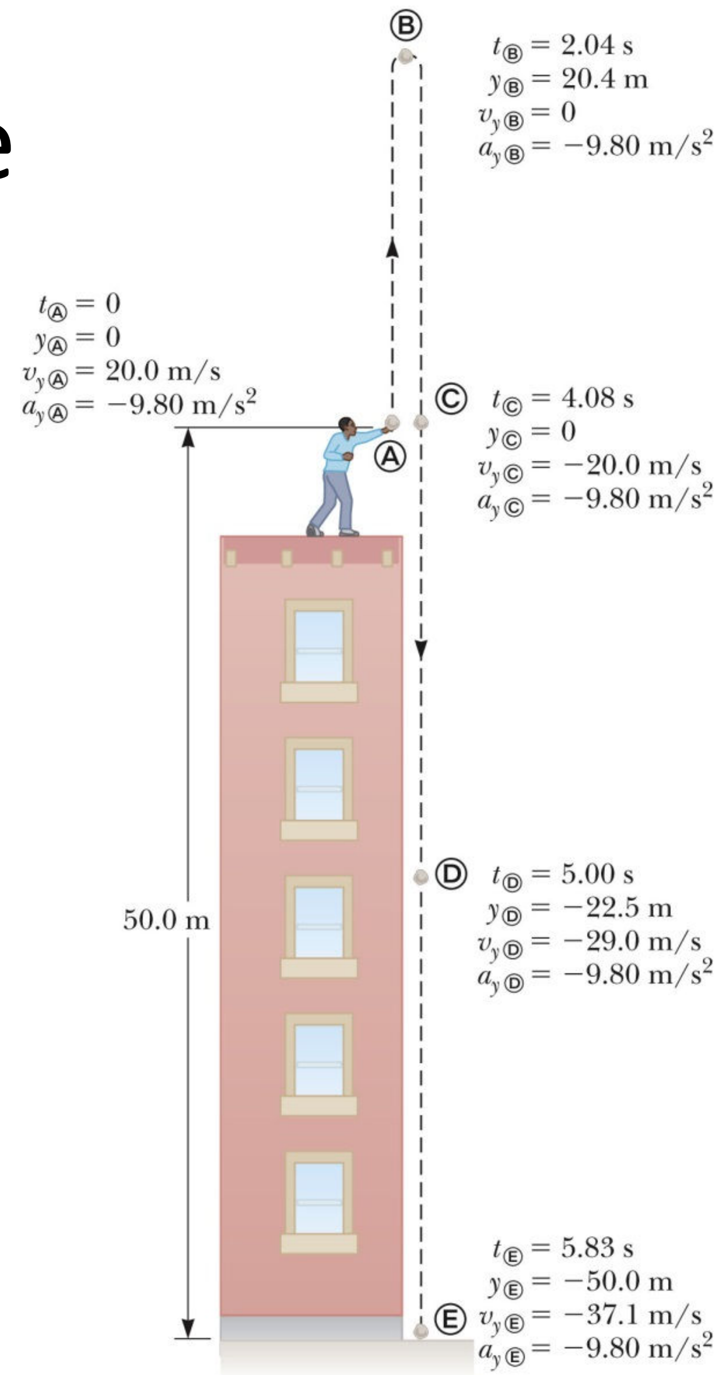


Thrown upward, cont.

- The motion may be symmetrical.
  - Then $t_{up} = t_{down}$
  - Then $v = -v_o$
- The motion may not be symmetrical.
  - Break the motion into various parts.
    - Generally up and down

Free Fall Example

- Initial velocity at A is upward (+) and acceleration is -*g* (-9.8 m/s^2).
- At B, the velocity is 0 and the acceleration is -*g* (-9.8 m/s^2).
- At C, the velocity has the same magnitude as at A, but is in the opposite direction.
- The displacement is –50.0 m (it ends up 50.0 m below its starting point).

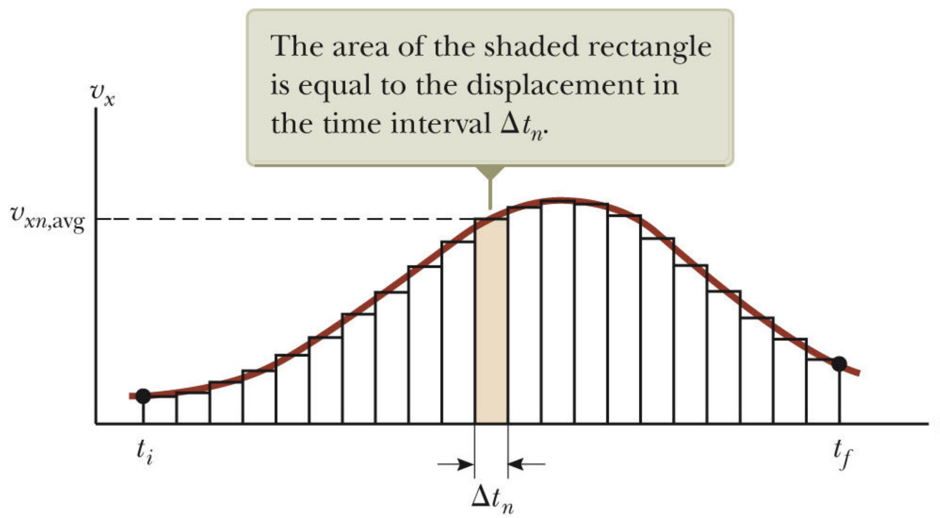


Kinematic Equations from Calculus

- Displacement equals the area under the velocity – time curve

$$\lim_{\Delta t_n \to 0} \sum_n v_{xn} \Delta t_n = \int_{t_i}^{t_f} v_x(t)\,dt$$

- The limit of the sum is a definite integral.



Kinematic Equations – General Calculus Form

$$a_x = \frac{dv_x}{dt}$$

$$v_{xf} - v_{xi} = \int_0^t a_x dt$$

$$v_x = \frac{dx}{dt}$$

$$x_f - x_i = \int_0^t v_x dt$$

Kinematic Equations – From Integration form

$$\frac{dv_x}{dt} = a_x = Const$$

- The integration form of $v_f - v_i$ gives

$$v_{xf} - v_{xi} = a_x t$$

- The integration form of $x_f - x_i$ gives

$$x_f - x_i = v_{xi} t + \frac{1}{2} a_x t^2$$

Problem solving strategies

- Draw a diagram, if appropriate.
- Write down what you know, and what you are trying to find.
- Solve things symbolically
  - It's quicker
  - Less likely to make a mistake
  - Solve it once and for all
  - General dependence of answer on various quantities
  - Can check units and limiting cases
- Check units/dimension
- Check limiting/special cases

Example

- An object starts from rest at $x_i = 0$ and moves for 10 s with an acceleration of $+2.0\ cm/s^2$. For the next 20 s, the acceleration is $-1.0\ cm/s^2$. What is position of the object at the end of this motion?

Draw a(t), v(t), x(t)

graphical method?

mathematial method

Summary

- 1D motion → Calculus of 1 variable
  - Slope of a curve = tangential limit (instantaneous velocity, instantaneous acceleration)
  - Importance of acceleration (2^{nd} derivative of x is related to a quantity called "force" which we will study very soon)
  - Once we know trajectory *x(t)*, we know everything else by rate of change: *x(t)→v(t) →a(t) via differential calculus*
  - Inversely, from knowledge of *a(t)*, the trajectory x(t) is uniquely determined by an initial condition {x(0),v(0)} via integral calculus
    - This yields Kinematic equations for the simple case where *a* = constant. The rest of problem-solving is purely algebraic.
- Goal: Calculus concept + Physics intuition