Physics 121.
Lecture 03.

Thor's Emerald Helmet. Credit & Copyright: Robert Gendler

A three-minute introduction to Engineers Without Borders

Physics 121.
Lecture 03.

- Topics:
  - Updated Course Information
  - Review of motion in one dimension
  - Motion in two dimensions:
    - Vectors
    - Position, velocity, and acceleration in two and three dimensions
    - Projectile motion

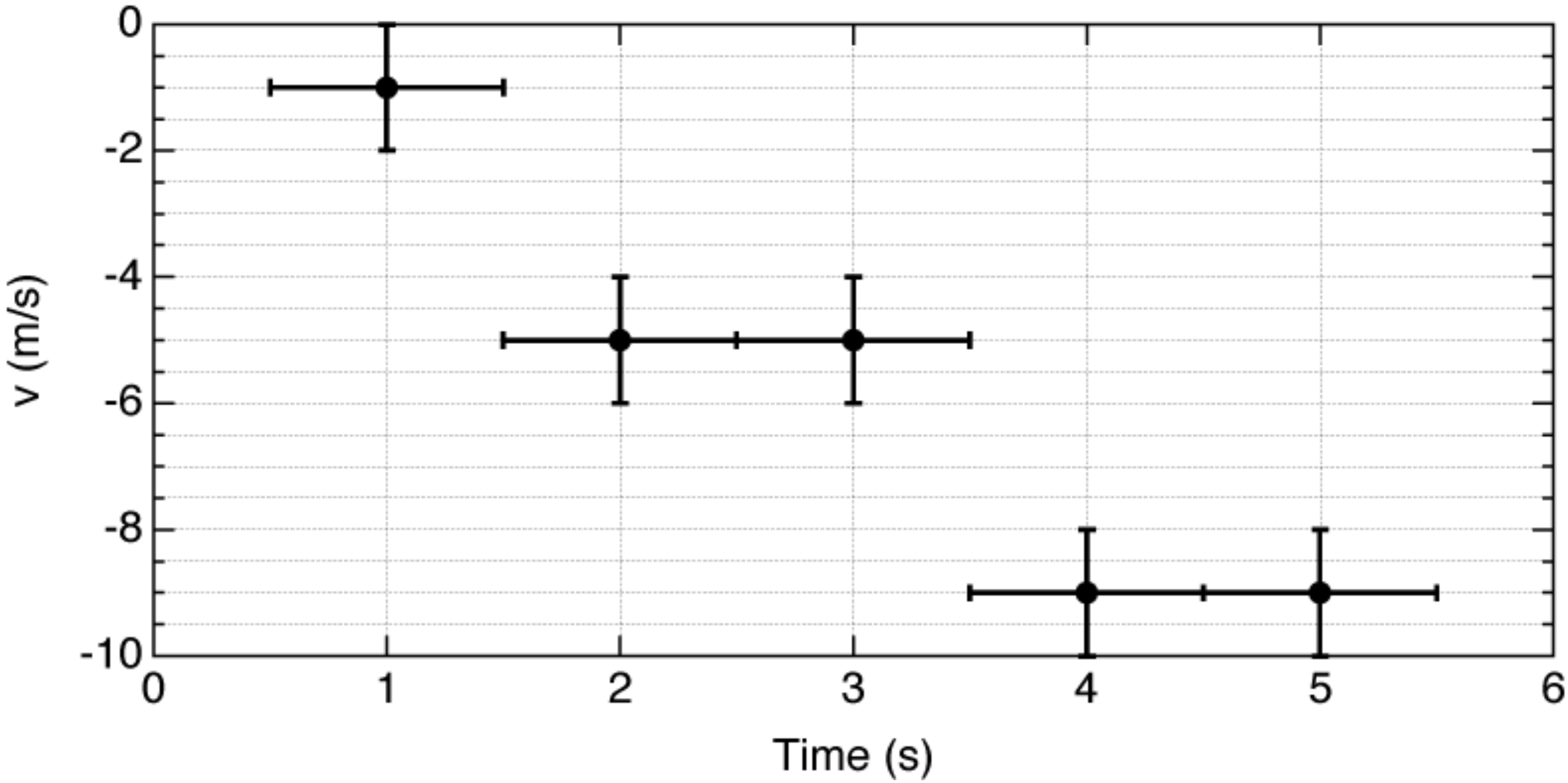
Physics 121
Updated course information

- The Physics 121 workshops started on Monday January 26.

- The physics 121 laboratories will start also on Monday February 2. You are required to complete all five experiments in order to get a grade for Physics 121. If you complete less than five experiments, you will get an incomplete (on average 15% of the Physics 121 students get an incomplete as a results of missing laboratory experiments).

- Homework set # 1 is due on Saturday 1/31/26 at 8.30 am. Do not wait until the last moment to start on this problem. Let's have a quick look at using spreadsheets to simplify your life!

Using spreadsheets to simplify your life!



Review of motion in one dimension.

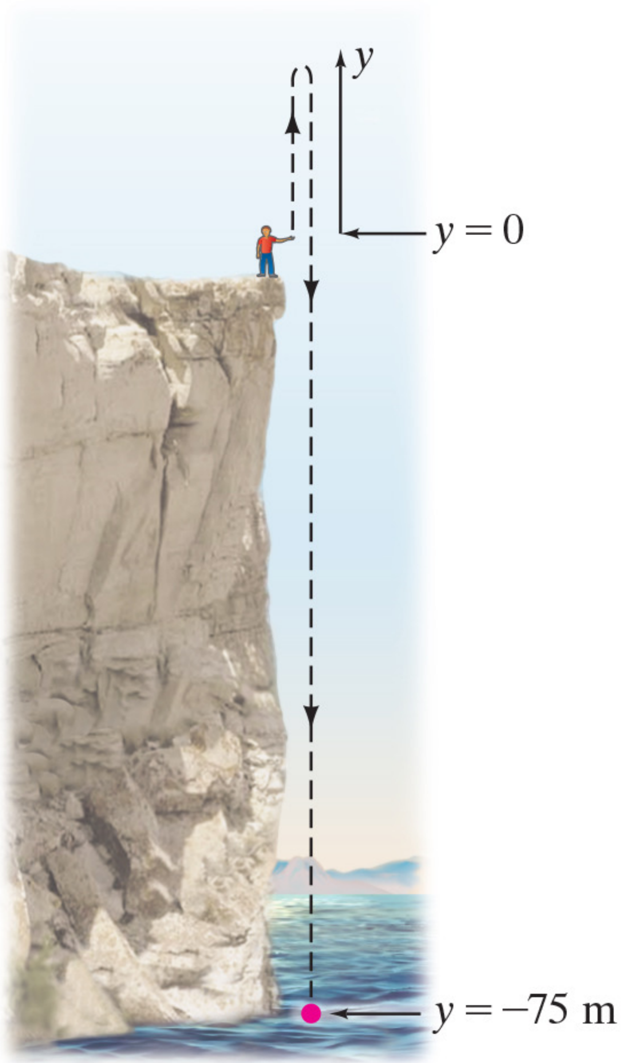
- Translational motion in one direction can describe the motion in terms of three parameters:
  - The position $x(t)$: units m.
  - The velocity $v(t)$: units m/s.
  - The acceleration $a(t)$: units m/s^2.
- An important special case is the case of constant acceleration (acceleration independent of time).

$$a = \frac{dv}{dt} = \text{constant}$$

$$v(t) = v_0 + at$$

$$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$$

Review of motion in one dimension.



$$a = \frac{dv}{dt} = -g$$

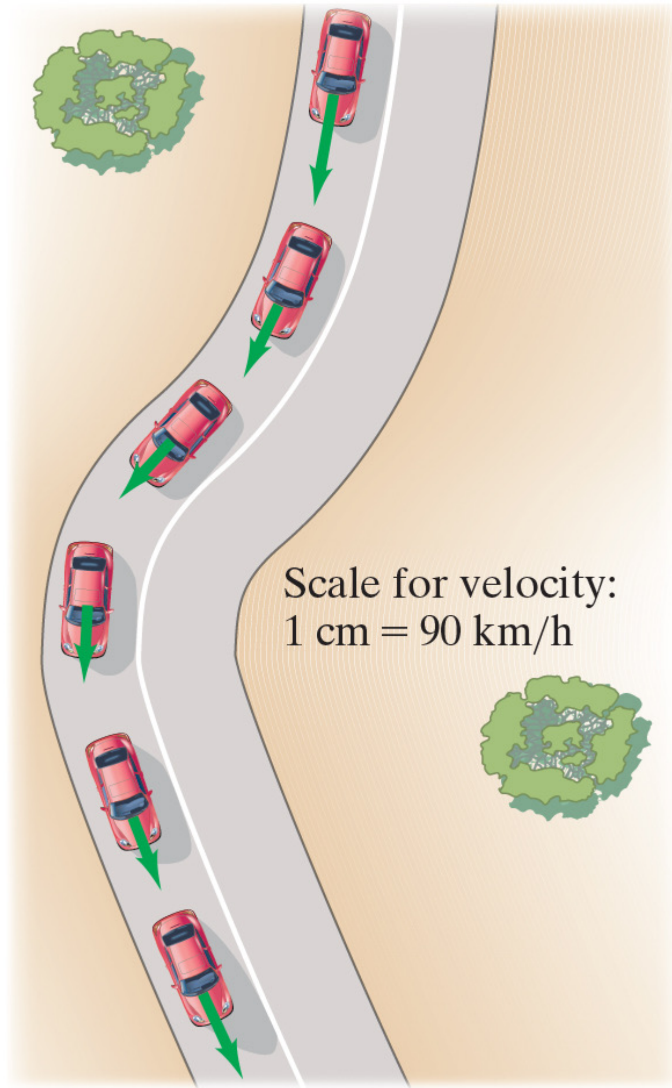
$$v(t) = v_0 - gt$$

$$y(t) = y_0 + v_0 t - \frac{1}{2} g t^2$$

Note: in this format, *g* is assumed to be the magnitude of the gravitational acceleration.

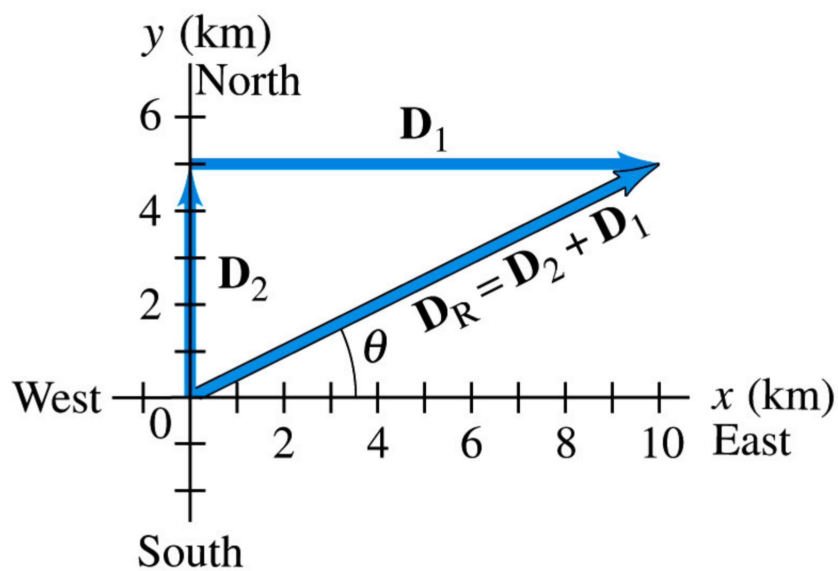
Motion in two or three dimensions. Vectors.

- In order to study motion in two dimensions, we need to introduce the concepts of vectors.
- Position, velocity, and acceleration in two- or three-dimensions are determined by not only specifying their magnitude, but also their direction.



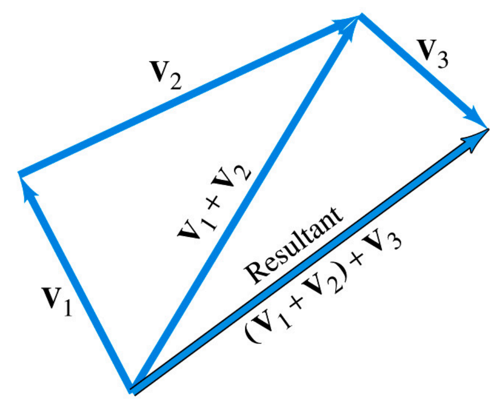
Two-dimensional motion.

- The same displacement can be achieved in many different ways.
- Instead of specifying a heading and distance that takes you from the origin of your coordinate system to your destination, you could also indicate how many km North you need to travel and how many km East.
- In either case, you need to specify two numbers and this type of motion is called two-dimensional motion.



Vector manipulations.

- Any complicated type of motion can be broken down into a series of small steps, each of which can be specified by a vector.
- I will make the assumption that you have read the details about vector manipulations:
  - Vector addition
  - Vector subtraction



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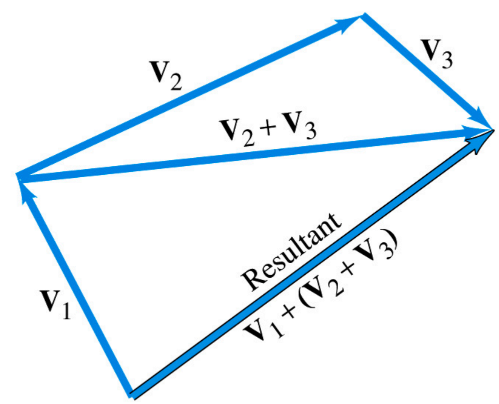
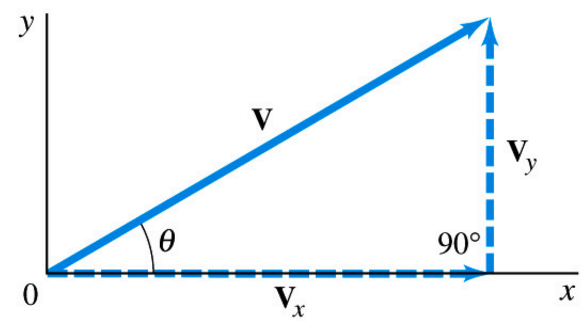


(c)

Vector components.

- Although we can manipulate vectors using various graphical techniques, in most cases the easiest approach is to decompose the vector into its components along the axes of the coordinate system you have chosen.

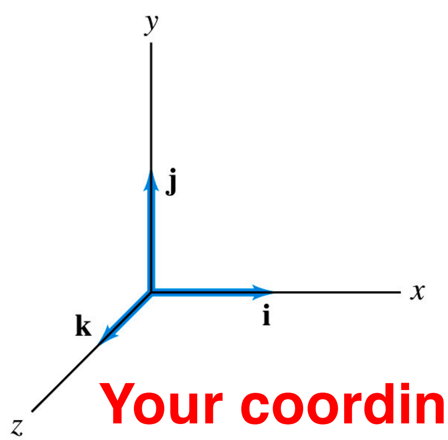


$$\sin\theta = \frac{V_y}{V}$$

$$\cos\theta = \frac{V_x}{V}$$

$$\tan\theta = \frac{V_y}{V_x}$$

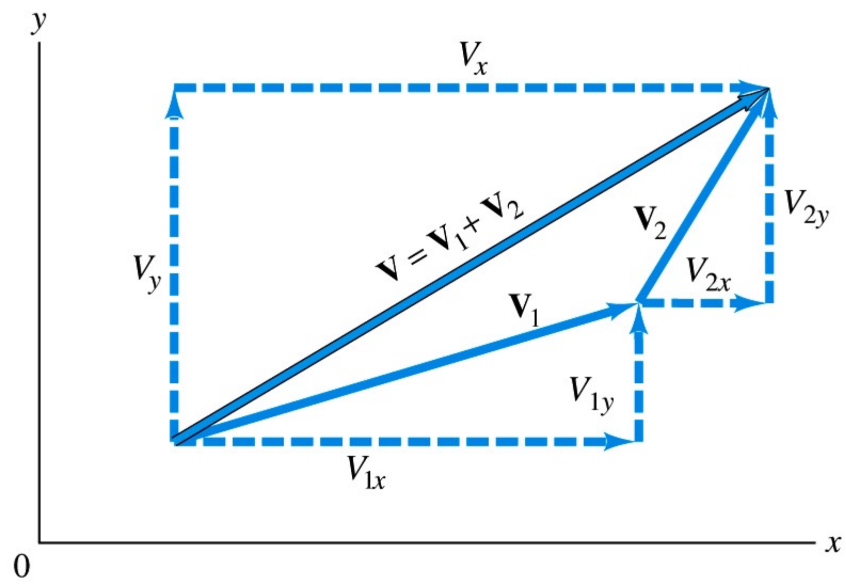
$$V^2 = V_x^2 + V_y^2$$



Your coordinate system needs to be right handed.

Vector components.

- Using vector components, vector addition becomes equivalent to adding the components of the original vectors.
- The sum of the *x* and *y* components can be used to reconstruct the sum vector.



3 Minute 31 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 31 second intermission.

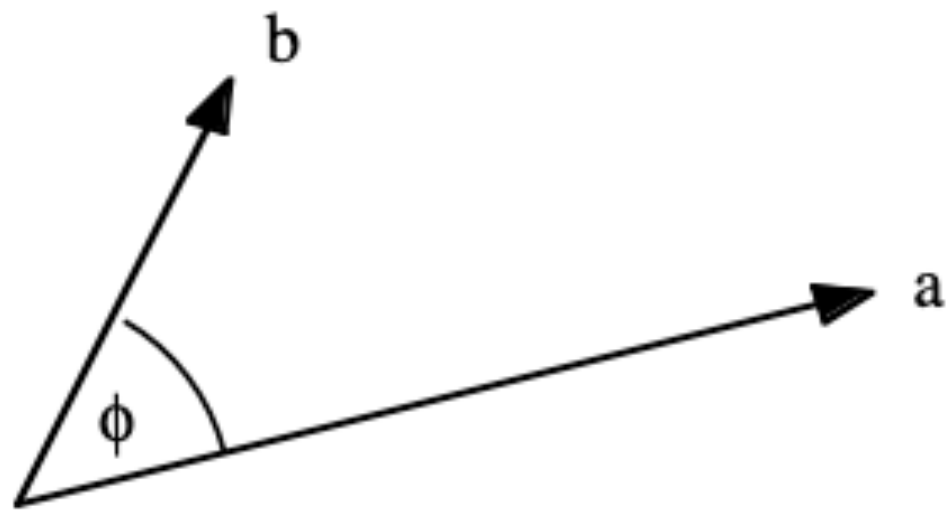
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWork problem.
  - Go asleep, as long as you wake up in 3 minutes and 31 seconds.

Other vector manipulations: the scalar product.

- The scalar product (or dot product) between two vectors is a scalar which is related to the magnitude of the vectors and the angle between them.

- It is defined as:

$$\vec{a} \cdot \vec{b} = |\vec{a}\,||\vec{b}|\cos\phi$$



Other vector manipulations: the scalar product.

- In terms of the components of $\vec{a}$ and $\vec{b}$, the scalar product is equal to

$$\vec{a}\cdot\vec{b} = \left(a_x\hat{\imath} + a_y\hat{\jmath} + a_z\hat{k}\right)\cdot\left(b_x\hat{\imath} + b_y\hat{\jmath} + b_z\hat{k}\right) =$$

$$= a_x b_x(\hat{\imath}\cdot\hat{\imath}) + a_y b_y(\hat{\jmath}\cdot\hat{\jmath}) + a_z b_z\left(\hat{k}\cdot\hat{k}\right) +$$

$$+(a_x b_y + a_y b_x)(\hat{\imath}\cdot\hat{\jmath}) + (a_x b_z + a_z b_x)(\hat{\imath}\cdot\hat{k}) +$$

$$+(a_y b_z + a_z b_y)\left(\hat{\jmath}\cdot\hat{k}\right) =$$

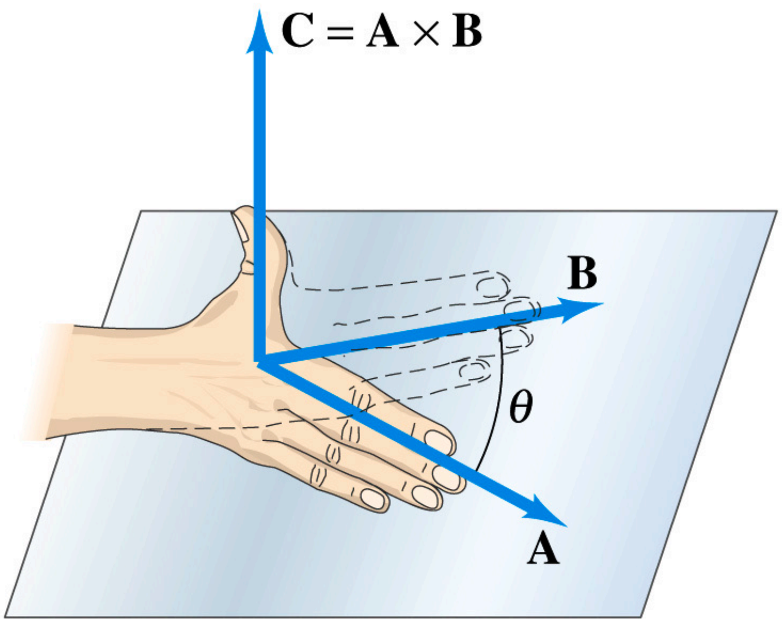
$$= a_x b_x + a_y b_y + a_z b_z$$

- Usually, you will use the component form to calculate the scalar product and then use the vector form to determine the angle between vectors $\vec{a}$ and $\vec{b}$.

Other vector manipulations: the vector product.

- The vector product between two vectors is a vector whose magnitude is related to the magnitude of the vectors and the angle between them, and whose direction is perpendicular to the plane defined by the vectors.
- The direction of the vector product is defined by the right-hand rule.
- The magnitude of the vector product is equal to

$$|\vec{c}| = |\vec{a}||\vec{b}|\sin\theta$$



Other vector manipulations: the vector product.

- Usually, the vector product is calculated by using the components of the vectors $\vec{a}$ and $\vec{b}$:

$$\vec{a}\times\vec{b} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} =$$

$$= \left(a_y b_z - a_z b_y\right)\hat{\imath} + \left(a_z b_x - a_x b_z\right)\hat{\jmath} + \left(a_x b_y - a_y b_x\right)\hat{k}$$

Defining motion in two dimensions.

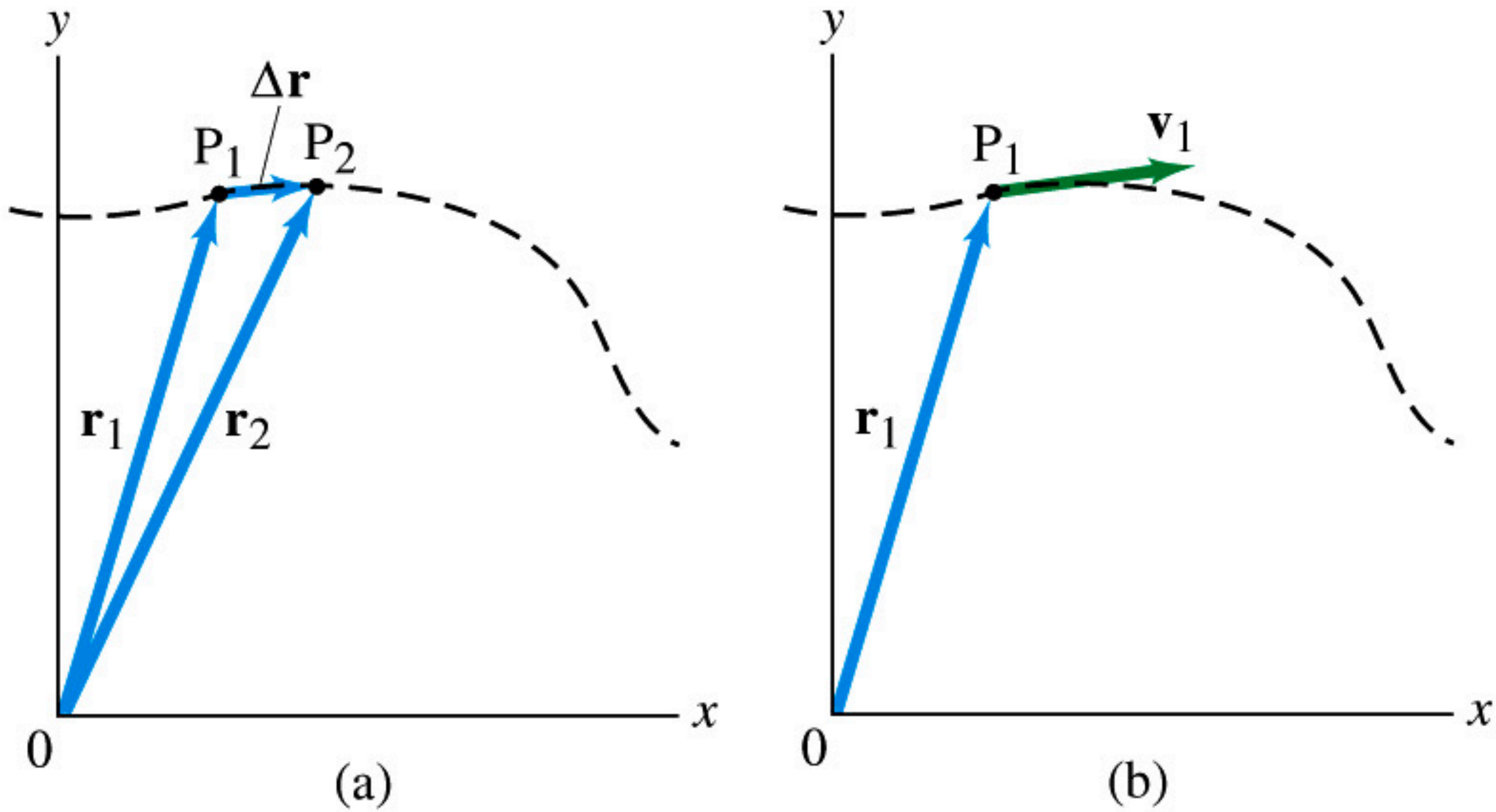
One Dimension

- Position x.
- Displacement Δx.
- Velocity: displacement per unit time. Sign is equal to the sign of the displacement Δx.
- Acceleration: change in velocity per unit time. Sign is equal to the sign of the velocity difference Δv.

Two/Three Dimensions

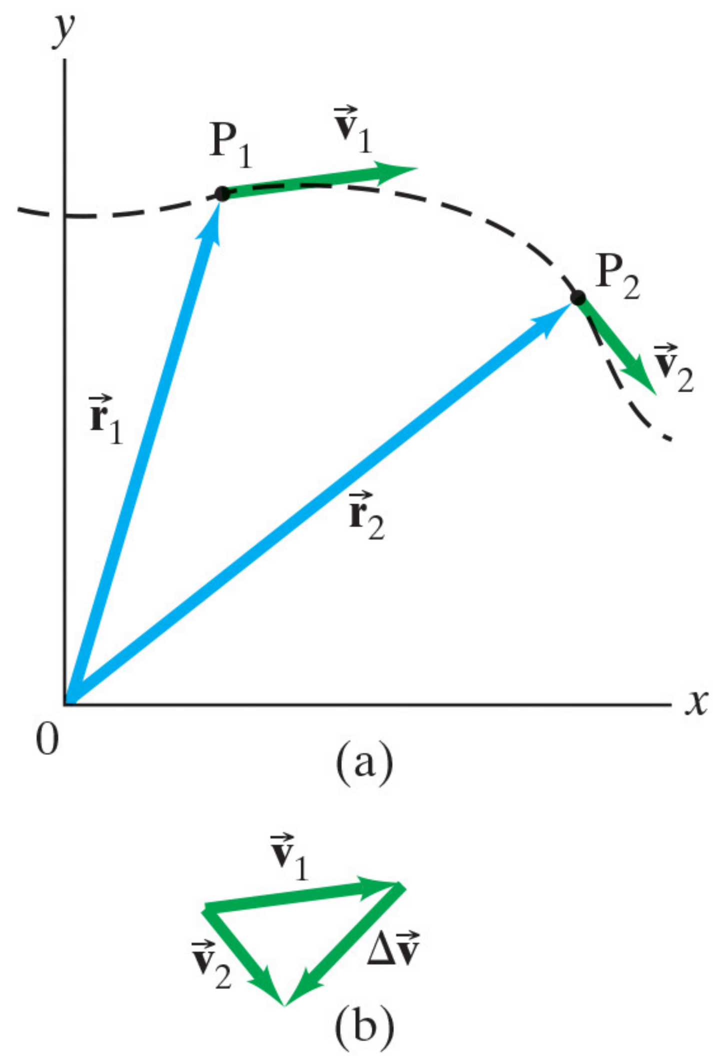
- Position vector $\vec{\boldsymbol{r}}$.
- Displacement vector $\Delta\vec{r}$.
- Velocity vector: change in the position vector per unit time. The direction is equal to the direction of the displacement vector $\Delta\vec{r}$.
- Acceleration vector: change in the velocity vector per unit time. The direction is equal to the direction of the velocity difference vector $\Delta\vec{v}$.

Motion in two dimensions.



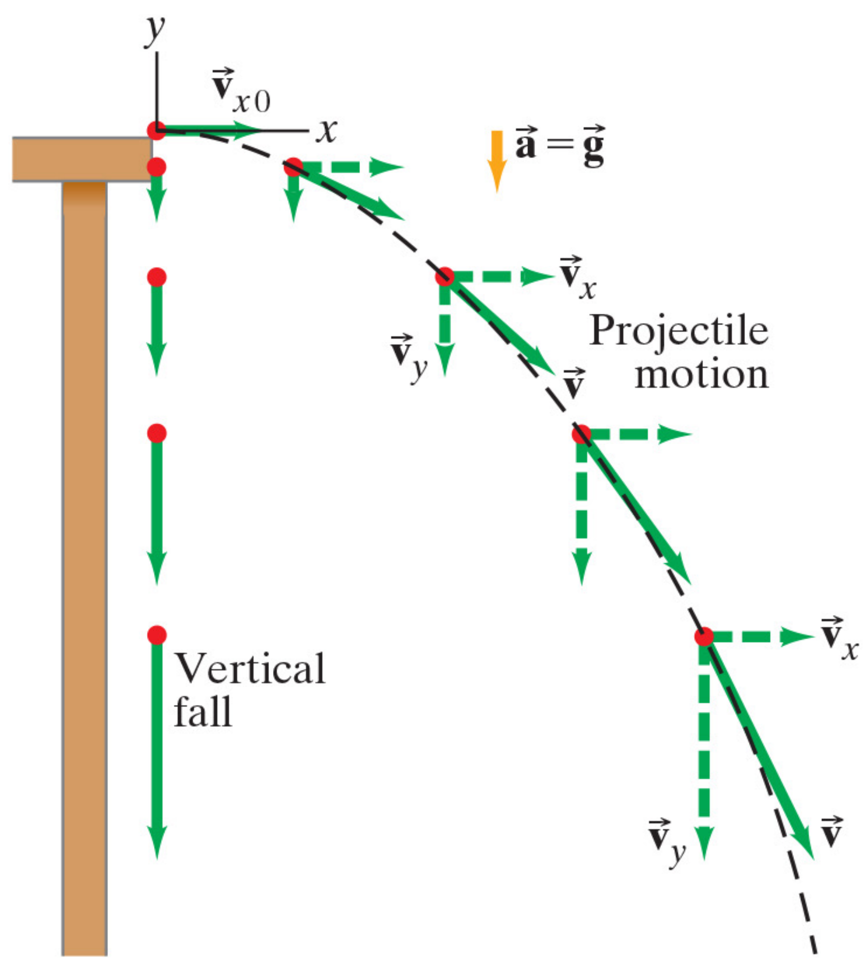
Motion in two dimensions.

- The direction of the velocity vector is tangent to the path of the object.
- The direction of the acceleration vector is more complicated and in general is not pointing in the same direction as the velocity.
- In non-zero acceleration in two or three dimensions does not need to result in a change of the speed of an object. It may only change the direction of motion and not its magnitude (circular motion).



Motion in two dimensions.

- When an object moves in two dimensions, we can consider two components of its motion separately.
- For example, in the case of projectile motion, the gravitational acceleration only influences the motion in the vertical direction.
- In the absence of an external force, there is no acceleration in the horizontal direction, and the velocity in that direction is thus constant.



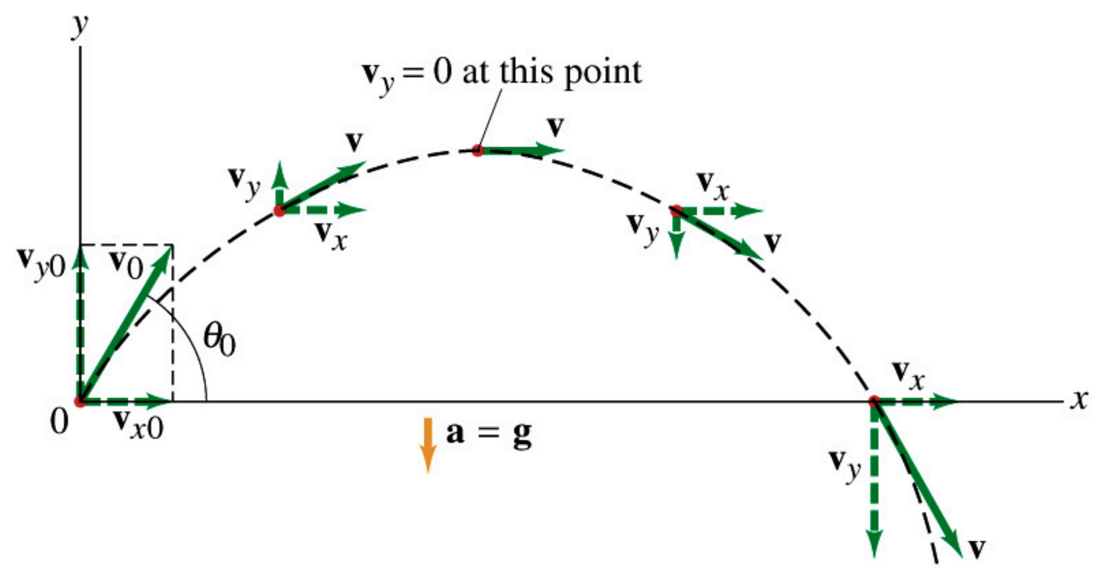
Motion in two dimensions.

- Let's practice what we just discussed.

Motion in two dimensions: projectile motion.

- To study projectile motion, we decompose the motion into its two components:
- Vertical motion:
  - Defines how long it will take for the projectile to hit the ground:

$$t = \frac{2v_0 \sin\theta_0}{g}$$



- Horizontal motion:
  - During this time interval, the distance traveled by the projectile is

$$x = (v_0 \cos\theta_0)\frac{2v_0 \sin\theta_0}{g} = \frac{v_0^2}{g}\sin 2\theta_0 = R$$

Motion in two dimensions: projectile motion.

- Let's practice what we just discussed.

Done!
Please review Chapter 4 before Thursday.

Adirondack Rock on Mars
Credit: Mars Exploration Rover Mission, JPL, NASA