Physics 8 — Friday, August 30, 2019

- Course www: `http://positron.hep.upenn.edu/physics8`
- You read Mazur Chapter 2 ("motion in one dimension") for today. I got online responses from 20/48 of you so far. Next week this should be 48/48! (I will start to pester you!)
- Over the long weekend, read Mazur Chapter 3 ("acceleration") and answer online questions at `http://positron.hep.upenn.edu/q008`
- And if you haven't yet **skimmed** Chapter 1 ("foundations"), please do so this weekend and answer the online questions.
- Then for next Wednesday, read Mazur Ch 4 ("momentum") and answer the online Q's. First few chapters go quickly!
- Homework #1 handout is in back of room (printed syllabus, too), in case you didn't get it Wednesday. It's due next Friday, at the start of class. It covers Chapters 1 and 2.
- Homework study/help sessions (optional):
  Greg will be in DRL 3C4 Wednesdays from 4–6pm.
  Bill will be in DRL 2C4 on Thursdays from 6–8pm.

Potential sources of confusion from today's reading

- It takes a while to get used to the textbook's vector notation. Some people positively hate the book's notation!
  - But the book's notation is extremely self-consistent, even if the many subscripts and superscripts are annoying.
  - And this book is excellent on the concepts.
- Also, it might take some practice to reacclimate your brain to reading lots of equations, if it has been several years since your last math course. No worries.
- What is a unit vector? Yuck!
- Using only a single spatial dimension (until Chapter 10) makes the discussion of vectors seem contrived.
- Distinction between displacement & position vectors.
- Difference between average and instantaneous velocity.
- We should return to this list, and perhaps update it, at the end of the hour.

Let's start by asking how your neighbor's answer to the first reading question compares with your own:

- What is a vector, and what is it good for?
- By the way, what are two examples of vectors that are focal points of chapter 2? (See what your neighbor says.)

Let's start by asking how your neighbor's answer to the first reading question compares with your own:

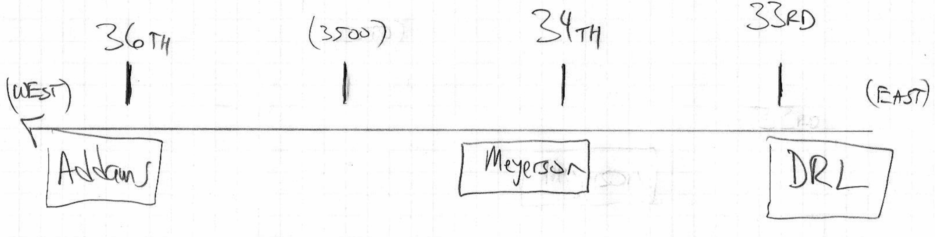
- What is a vector, and what is it good for?
- By the way, what are two examples of vectors that are focal points of chapter 2? (See what your neighbor says.)
- Here's what one of you wrote:

"A vector quantity, unlike a scalar quantity, is one that not only has a magnitude but also a direction. An example of an important vector quantity is displacement — unlike distance, displacement takes into account the direction that something has travelled in (i.e. while someone may have run a 400 m distance on a track, their displacement would be 0 since they end up back where they started.)"

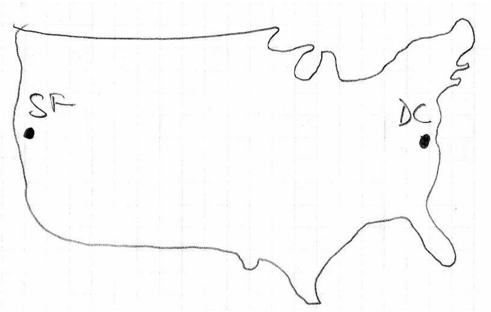
By the way: clear and complete answers make me very happy.

Vectors

- A **vector** has both a magnitude and a spatial direction, e.g. up, north, east, etc.
- The **position** $\vec{r}$ is a vector (x, y, z) pointing from the origin $(0, 0, 0)$ to the object's location in space. $\vec{r}$ indicates where the object is with respect to $x = 0$, $y = 0$, $z = 0$.
- You may be familiar with vectors written as triplets (x, y, z), or with arrows, $\vec{r} = (x, y, z)$.
- The **components** of this vector are
  $r_x = x$ (the x component),
  $r_y = y$ (the y component), and
  $r_z = z$ (the z component).
- The **magnitude** of vector $\vec{r}$ is $|\vec{r}| = r = \sqrt{x^2 + y^2 + z^2}$ (but we won't see that until Chapter 10).
- But for the first 9 chapters, we will deal only with the x axis. Once we reach chapter 10, we'll use x and y axes together. So no $\sqrt{x^2 + y^2}$ until then.



- What is the distance (in blocks) between DRL and Addams?
- If you walk in a straight line that starts at DRL and ends at Addams, what is your distance traveled (in blocks)?
- What is your displacement (expressed using blocks and a compass direction)?
- If you start at Addams and end at DRL, what is your displacement?
- What is your distance traveled in that case?
- If you start at Addams, walk to Meyerson, walk back to Addams, then walk to DRL (ending there), what is your displacement?
- What is your distance traveled?



- What is (roughly) the distance between SF and DC?
- If you start in SF and end in DC, what is your displacement?
- Which one is a vector?
- How does the distance between SF and DC relate to the displacement from SF to DC?
- How does the distance between SF and DC relate to the displacement from DC to SF?
- For a journey on which I go in a straight line, never changing direction, how are “distance” and “distance traveled” related?
- For a journey on which I do change direction several times, how can I figure out the distance traveled?

Position, displacement, etc.

- A **vector** has both a magnitude and a spatial direction, e.g. up, north, east, etc.
- The **position** $\vec{r}$ is a vector (x, y, z) pointing from the origin $(0, 0, 0)$ to the object's location in space. $\vec{r}$ indicates where the object is with respect to $x = 0$, $y = 0$, $z = 0$.
- If an object moves from some initial position $\vec{r}_i$ to some final position $\vec{r}_f$, we say its **displacement** (vector) is $\Delta\vec{r} = \vec{r}_f - \vec{r}_i$, pointing from its initial position $\vec{r}_i$ to its final position $\vec{r}_f$.
- The x **component** of the displacement is $x_f - x_i$.
- The **distance** (scalar) between $\vec{r}_i$ and $\vec{r}_f$ is $d = |\Delta\vec{r}| = |\vec{r}_f - \vec{r}_i|$. In one dimension, $d = |x_f - x_i|$.
- We'll be reminded in Chapter 10 that in two dimensions, $d = \sqrt{(x_f - x_i)^2 + (y_f - y_i)^2}$. For now we use 1D.

Position, displacement, etc.

- The **distance** (scalar) between $\vec{r}_i$ and $\vec{r}_f$ is $d = |\Delta\vec{r}| = |\vec{r}_f - \vec{r}_i|$. In one dimension, $d = |x_f - x_i|$.
- If the object does not change direction between $\vec{r}_i$ and $\vec{r}_f$, then the **distance traveled** is the same as d.
- If the object changes direction at (for example) points a,b,c along the way, then the **distance traveled** is

$$d_{\text{traveled}} = |\vec{r}_a - \vec{r}_i| + |\vec{r}_b - \vec{r}_a| + |\vec{r}_c - \vec{r}_b| + |\vec{r}_f - \vec{r}_c|$$

- In one dimension, the distanced traveled for this case (turning at three points a,b,c) would be

$$d_{\text{traveled}} = |x_a - x_i| + |x_b - x_a| + |x_c - x_b| + |x_f - x_c|$$

- If someone asks you how to get from DRL to 30th Street Station, is it sufficient to say (without pointing), "Go 5 blocks?"
- Is it good enough to say, "Go 2 blocks, then go another 3 blocks?"
- What about "Go 2 blocks north, then go 3 blocks east?"
- Once again, for the first 9 chapters of the textbook, directions will be **either** north/south **OR** east/west **OR** up/down, but we will not (until Chapter 10) work with more than one axis in a given problem.
- (Also, somewhat confusingly, for the first 9 chapters, the one axis that we do work with will always be called **the x axis**, even if it does not point in a direction that you are accustomed to associating wth the x axis.)
- So we won't worry, until Chapter 10, about things like the fact that a bird could travel from DRL to 30th Street Station along a diagonal that is $\sqrt{13}$ blocks long.

For next few questions

(I'll copy this to the board.)

(A) $+5$ meters

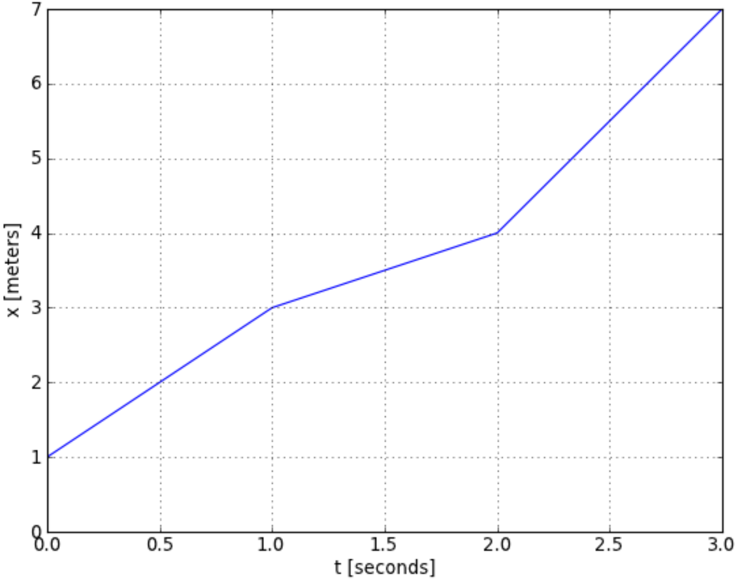
(B) $+6$ meters

(C) $+8$ meters

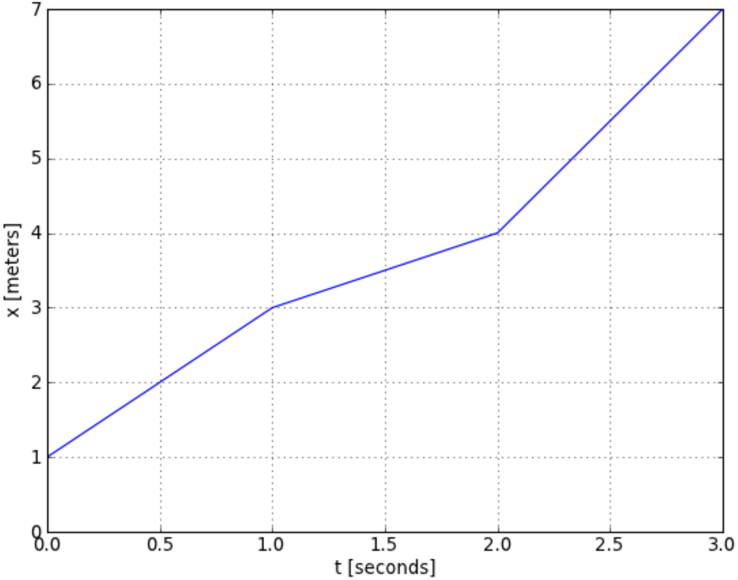
(D) -6 meters

(E) -8 meters

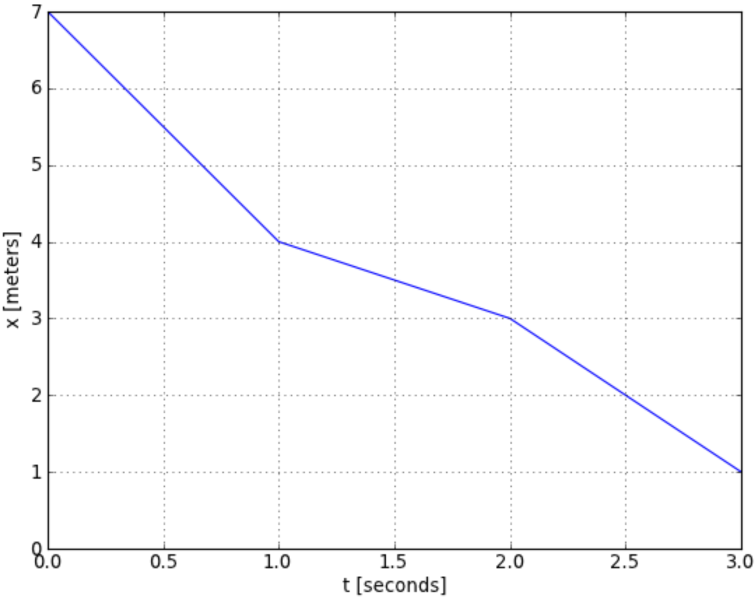
What is the distance traveled from t=0 to t=3s?



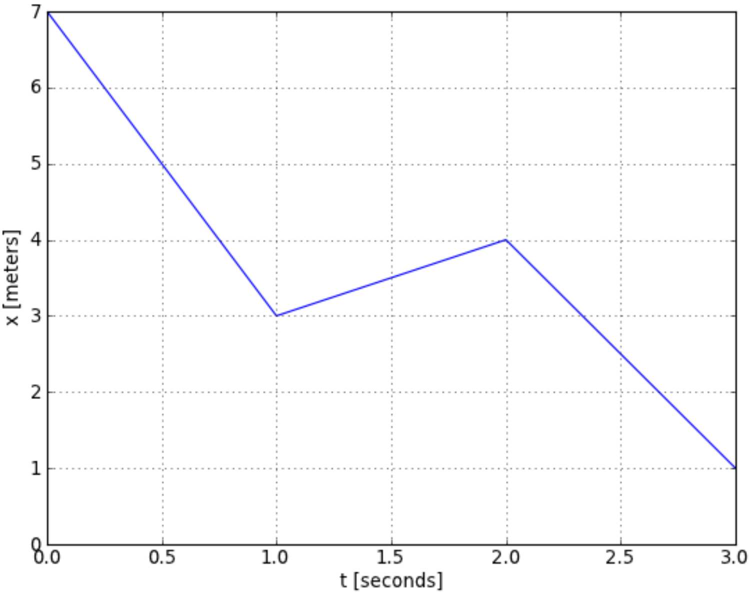
What is the x component of displacement?



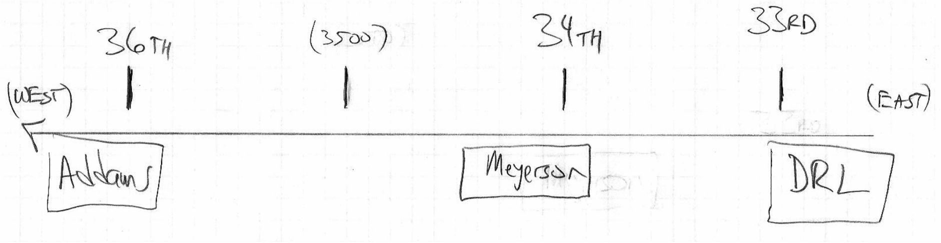
Now what is the x component of displacement?



Now what is the distance traveled?



To keep the math simple, let's pretend that every city block is exactly 100 meters long.



- If I bike directly from DRL to Addams in 100 seconds, what is my average speed?
- What is my average velocity?
- If I walk directly from DRL to Addams in 200 seconds, then bike directly back from Addams to DRL in 100 seconds, what is my average velocity for the journey?
- What is my average speed for the journey?

- What is the relationship between (instantaneous) speed and (instantaneous) velocity?
- What does calculus say about the relationship between speed and distance traveled? (Does one of them equal the rate of change of the other?)
- What does calculus say about the relationship between displacement and velocity? (Does one of them equal the rate of change of the other?)

Velocity and speed

- **Velocity** (a vector) is the rate of change of position with respect to time: $\vec{v} = \frac{\mathrm{d}\vec{r}}{\mathrm{d}t} = (v_x, v_y, v_z) = (\frac{\mathrm{d}x}{\mathrm{d}t}, \frac{\mathrm{d}y}{\mathrm{d}t}, \frac{\mathrm{d}z}{\mathrm{d}t})$
- **speed** $v = |\vec{v}|$ is magnitude (scalar) of velocity (vector)
- In one dimension, speed is $v = |v_x|$, i.e. the absolute value of the x-component of velocity.
- We can talk about velocity at a given instant. Over a finite time interval, we can talk about the **average velocity** during the time from t_i to t_f.

$$\vec{v}_{\mathrm{av}} = \frac{\Delta\vec{r}}{t_f - t_i} \qquad v_{x,\mathrm{av}} = \frac{x_f - x_i}{t_f - t_i}$$

- The **average speed** during the finite time interval from t_i to t_f is the (distance traveled) divided by the (time interval)

$$v_{\mathrm{av}} = \frac{d_{\mathrm{traveled}}}{t_f - t_i}$$

Example 2.9 (modified)

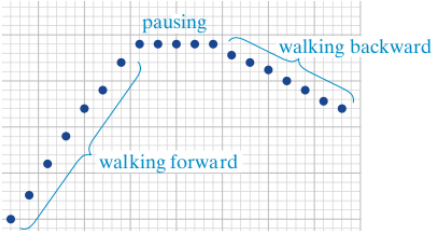
frame #	x (m)	t (s)
1	+1.0	0
2	+1.5	0.33
3	+2.2	0.67
4	+2.8	1.00
5	+3.4	1.33
6	+3.8	1.67
7	+4.4	2.00
8	+4.8	2.33
9	+4.8	2.67
10	+4.8	3.00
11	+4.8	3.33
12	+4.8	3.67
13	+4.6	4.00
14	+4.4	4.33
15	+4.2	4.67
16	+4.0	5.00
17	+3.8	5.33
18	+3.6	5.67
19	+3.4	6.00

Consider Eric's motion between frames 13 and 19 in textbook Figure 2.1. Let's use the values in Table 2.1 to answer to these questions:

(a) What is his average speed over this time interval?

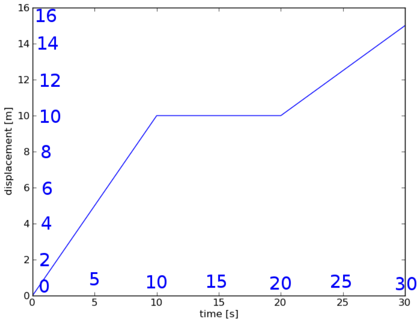
(b) What is the x component of his average velocity over this time interval?

(c) Write the average velocity (during this time interval) in terms of the unit vector $\hat{\imath}$.



Drawing position (or displacement) vs. time

Which statement best describes the motion depicted by this graph?



(A) I walk 1.0 m/s forward for 10 s. Then I rest 10 s. Then I walk 1.0 m/s backward for 10 s.

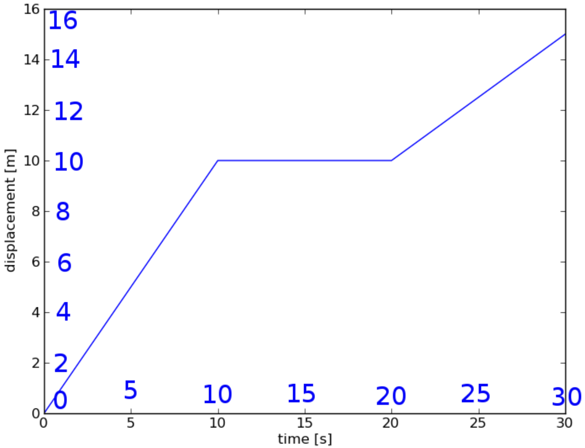
(B) I walk 0.5 m/s forward for 10 s. Then I rest 10 s. Then I walk 1.0 m/s forward for 10 s.

(C) I walk 0.5 m/s forward for 10 s. Then I rest 10 s. Then I walk 0.5 m/s forward for 10 s.

(D) I walk 1.0 m/s forward for 10 s. Then I rest 10 s. Then I walk 0.5 m/s forward for 10 s.

Average velocity

What is my average velocity $\vec{v}_{\text{av}}$ during the 30 second interval shown on this graph? (Remember that $\hat{i}$ is the unit vector pointing forward along the x axis, i.e. pointing in the direction in which x increases.)



(A) $+1.0$ m/s $\hat{i}$

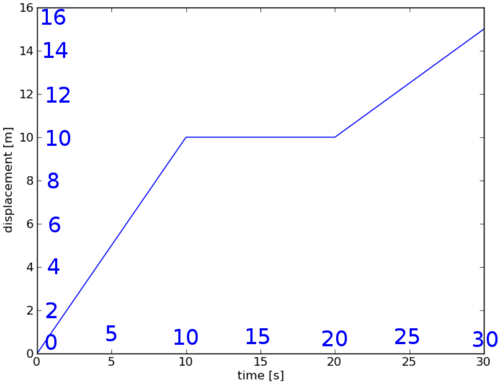
(B) $+0.75$ m/s $\hat{i}$

(C) $+0.5$ m/s $\hat{i}$

(D) -0.25 m/s $\hat{i}$

Instantaneous velocity

What is my instantaneous velocity $\vec{v}$ at time $t = 5$ s? What is $\vec{v}$ at time $t = 15$ s?



(A) $+1.0$ m/s $\hat{i}$ and 0 m/s $\hat{i}$, respectively

(B) $+0.5$ m/s $\hat{i}$ and $+1.0$ m/s $\hat{i}$, respectively

(C) $+1.0$ m/s $\hat{i}$ and $+0.5$ m/s $\hat{i}$, respectively

(D) $+0.5$ m/s $\hat{i}$ and $+0.5$ m/s $\hat{i}$, respectively

Slope of the x(t) curve

The slope of the curve in the x coordinate of position vs. time graph (graph of $x(t)$ vs. t) for an object's motion gives

(A) the object's speed

(B) the object's acceleration

(C) the object's average velocity

(D) the x component of the object's instantaneous velocity

(E) not covered in today's material

You walk 1.2 km (1200 m) due east from home to a restaurant in 20 min (1200 s), stay there for an hour (3600 s), and then walk back home, taking another 20 min. What is your **average speed** for the trip?

(A) $v_{\mathrm{av}} = 0.0\ \mathrm{m/s}$

(B) $v_{\mathrm{av}} = 0.4\ \mathrm{m/s}$

(C) $v_{\mathrm{av}} = 0.8\ \mathrm{m/s}$

(D) $v_{\mathrm{av}} = 1.0\ \mathrm{m/s}$

(E) $v_{\mathrm{av}} = 2.0\ \mathrm{m/s}$

You walk 1.2 km (1200 m) due east from home to a restaurant in 20 min (1200 s), stay there for an hour (3600 s), and then walk back home, taking another 20 min. What is your **average velocity** for the trip?

(A) $\vec{v}_{\rm av} = \vec{0}$

(B) $\vec{v}_{\rm av} = +0.4\ \rm m/s$ east

(C) $\vec{v}_{\rm av} = +0.8\ \rm m/s$ east

(D) $\vec{v}_{\rm av} = -0.4\ \rm m/s$ east

(E) $\vec{v}_{\rm av} = -0.8\ \rm m/s$ east

You drive an old car on a straight, level highway at 20 m/s for 20 km, and then the car stalls. You leave the car and, continuing in the direction in which you were driving, walk to a friend's house 4 km away, arriving 1000 s after you began walking. What is your average speed during the whole trip?

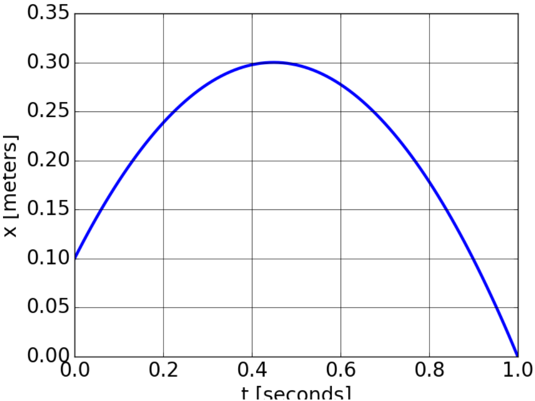
(A) $v_{\rm av} = 10\ \rm m/s$

(B) $v_{\rm av} = 12\ \rm m/s$

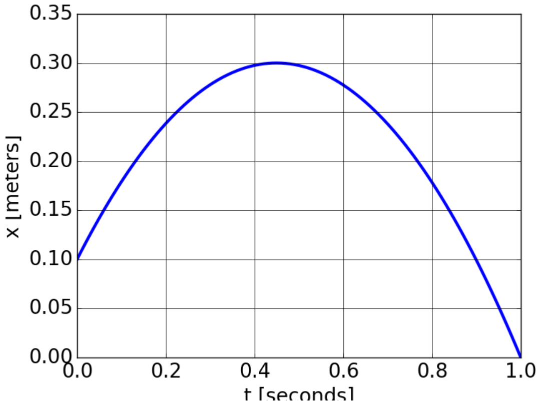
(C) $v_{\rm av} = 15\ \rm m/s$

(D) $v_{\rm av} = 20\ \rm m/s$

(E) $v_{\rm av} = 24\ \rm m/s$



- Where is the object moving forward?
- Where is the object moving backward?
- Where does the speed equal zero?
- Where is the speed largest?
- Where is v_x (the x component of velocity) largest?



For the motion represented in the figure above, what is the object's average velocity between $t = 0$ and $t = 1.0\,\mathrm{s}$?

What is its average speed during this same time interval?

Why is the average speed, for this motion, different from the magnitude of the average velocity?

We stopped here on Friday. We'll spend the first few minutes on Wednesday finishing Chapter 2 before we start Chapter 3.

Unit vectors (yuck)

- We can define **unit vectors** in the x, y, and z directions: $\hat{i} = (1, 0, 0)$, $\hat{j} = (0, 1, 0)$, and $\hat{k} = (0, 0, 1)$.
- Then we can write $\vec{r} = (x, y, z) = x\hat{i} + y\hat{j} + z\hat{k}$.
- It's often convenient to define a coordinate system where the x-axis points east, the y-axis points north, and the z-axis points up, with the origin at some specified location (e.g. the center of the ground floor).
- Then if I'm standing 5 meters east of the origin, my position vector is $+5\,\mathrm{m}\ \hat{i}$, which we could also write as $(+5\,\mathrm{m}, 0, 0)$.
- If I'm 3 m west of the origin, then $\vec{r} = -3\,\mathrm{m}\ \hat{i} = (-3\,\mathrm{m}, 0, 0)$.
- If I'm 2 m north of the origin, then my position is $\vec{r} = +2\,\mathrm{m}\ \hat{j} = (0, +2\,\mathrm{m}, 0)$.
- Most students dislike Mazur's unit-vector notation, so I try to avoid using it. I will instead write, "The displacement is +5 meters eastward." I will usually use a word like "east" or "north" or "up" to avoid writing $\hat{i}$ or other unit vectors.

Vectors

- Vectors are very useful on a 2D map ((x, y) or geocode) or in a 3D CAD model (x, y, z).
- For the first 10 chapters of our textbook, all problems will be one-dimensional (we will use the x-axis only), which makes the use of vectors seem contrived at this stage.
- The reason for doing this is so that we can focus on the physics first before reviewing too much math.
- In one dimension, position is $\vec{r} = (x, 0, 0) = x\ \hat{i}$.
- The x component of vector $\vec{v}$ is v_x, and in one dimension $\vec{v} = (v_x, 0, 0) = v_x\ \hat{i}$.
- The x component of vector $\vec{r}$ is x. (Special case notation.)
- In 1D, magnitude of $\vec{r}$ is $|x|$, and magnitude of $\vec{v}$ is $|v_x|$.
- Vectors will seem more natural starting in Chapter 10, when we study motion in a two-dimensional plane.

- **position:** where is it located in space? $\vec{r} = (x, y, z)$
- **displacement:** where is it w.r.t. some earlier position?
- $\Delta\vec{r} \;=\; (\Delta x, \Delta y, \Delta z) \;=\; \Delta x\hat{\imath} + \Delta y\hat{\jmath} + \Delta z\hat{k}$
- position and displacement are both **vectors**: they have both a direction in space and a magnitude
- **distance** is a scalar (magnitude only, never negative)
- **unit vectors** $\hat{\imath} = (1, 0, 0)$, $\hat{\jmath} = (0, 1, 0)$, $\hat{k} = (0, 0, 1)$ are vectors pointing along x,y,z axes, with "unit" magnitude (length = 1). Until Chapter 10, we use only the x-axis. So $\hat{\imath}$ is the only unit vector introduced in Chapter 2.
- **average velocity** $\vec{v}_{\rm av} = \frac{\Delta\vec{r}}{\Delta t}$: (displacement) / (time interval) x-component of $\vec{v}_{\rm av}$ is $v_{x,\rm av} = \frac{\Delta x}{\Delta t}$
- **(instantaneous) velocity** $\vec{v} = \frac{{\rm d}\vec{r}}{{\rm d}t} = (\frac{{\rm d}x}{{\rm d}t}, \frac{{\rm d}y}{{\rm d}t}, \frac{{\rm d}z}{{\rm d}t})$ x-component of $\vec{v}$ is $v_x = \frac{{\rm d}x}{{\rm d}t}$
- velocity is a vector (it has a direction in space), **speed** is a scalar (it has only a magnitude)
- For many people, the hardest part of this reading is getting used to the author's notation.

Potential sources of confusion from today's reading

- It takes a while to get used to the textbook's vector notation. Some people positively hate the book's notation!
  - But the book's notation is extremely self-consistent, even if the many subscripts and superscripts are annoying.
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- Anything to add to this list?

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