Lecture 2 / Day 1 Motion and Kinematics

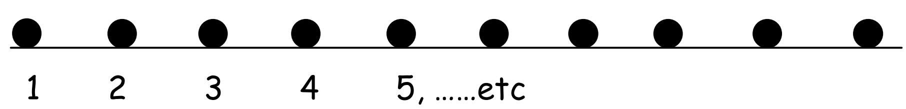
Intro. Motion Diagrams
Vector Subtraction
Velocity

We've gone through the basics of measurement and using vectors – now we're ready to get into Kinematics, which is the study of motion without really considering what causes the motion. We'll talk about what causes the motion when we get into Forces and Motion.

You should be prepared to tackle some tough ideas in kinematics – When these ideas were first conceived, it was a huge intellectual hurdle for even the best physicists.

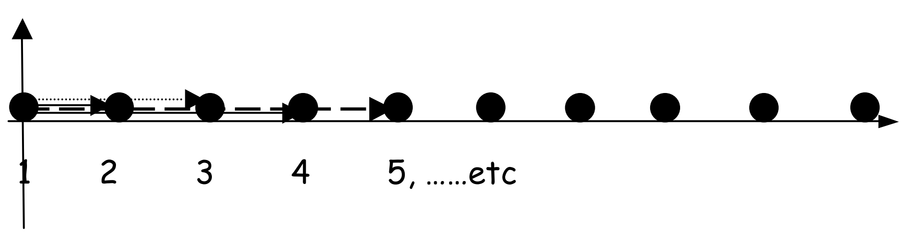
So to begin, we'll introduce the idea of a motion diagram. Think of watching a ball thrown across the room. In the room there's a strobe light, so you see successive "pictures" of the ball instead of one continuous motion. Let's do an example. [Have a volunteer walk with constant speed across the front of the room. Tape a dot to the volunteer, have students watch the dot.]

We can make a motion diagram of the student walking across the room:



Notice the points are equally spaced. Why is this?

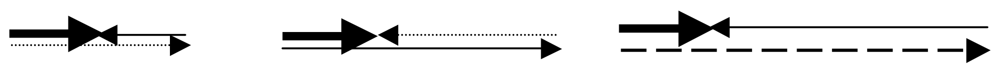
Now let's add to our diagram:



We've added a vertical and horizontal axis to define the origin of our motion. This is where position (x and y) are equal to zero.

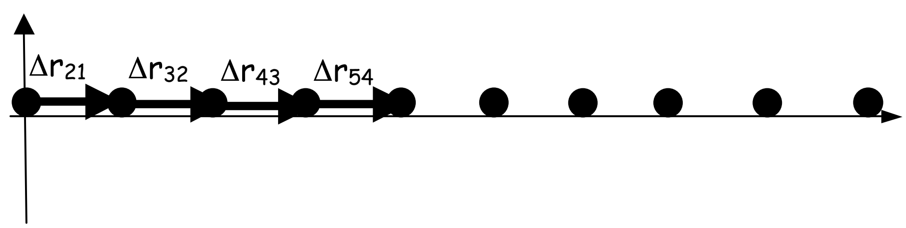
The arrows we've drawn show the displacement from the origin.
Displacement is a directed distance. Instead of saying, Joe went 3 meters away from the origin, we say Joe went 3 meters to the right. Displacement is a vector – it has a magnitude and direction.

For our diagram, we want to know the displacement between units of time (i.e. between dots), not just the displacement from the origin. This is easy now that we know how to add and subtract vectors.

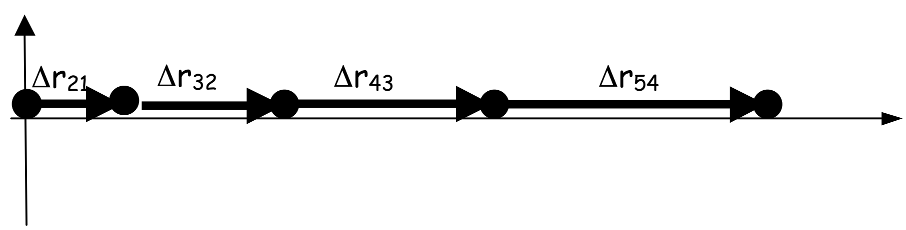


$\Delta r_{32} = r_3 - r_2$ $\Delta r_{43} = r_4 - r_3$ $\Delta r_{54} = r_5 - r_4$

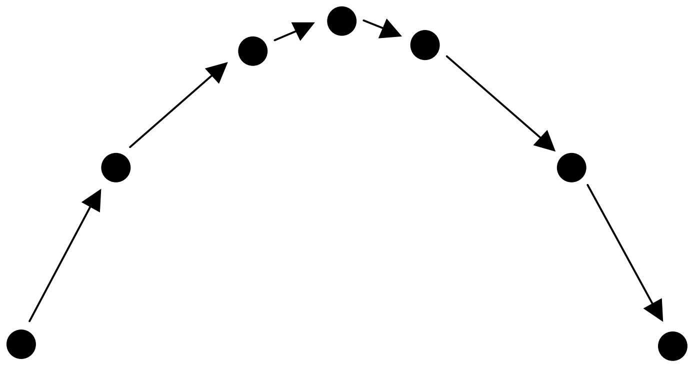
Notice that all the Δr vectors are of equal length. Hopefully, not a startling conclusion. Now we can label them on the diagram. (* Point of clarification: Δ means final minus initial)



Now let's tackle some other motions. [Have a volunteer walk with increasing speed across the front of the room.]
You now draw your own diagrams, and when you're done share them with you neighbors – comparing similarities and differences.

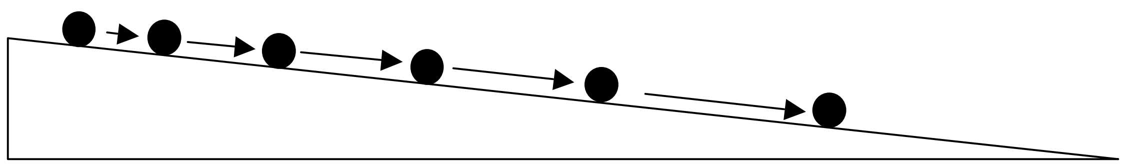


The displacement vectors become increasingly larger because the ball moves faster – it covers more distance each time you take a snapshot of it. Let's analyze the motion of something a little more interesting – a projectile. Again, draw your own diagram and when you're done share with your neighbors. Also, it's important to know when to start the diagram and when to stop. After the object leaves the influence of the hand and right before it hits the ground or is stopped by an external force. Basically, we only look at the time that it is not subject to external force.

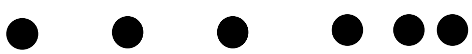


Notice how the shape changes and speed changes – it slows through the middle and gets faster toward the bottom.

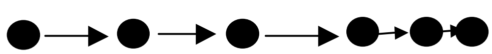
Let's look at a ball rolling down an incline:



So now that we've mastered motion diagrams, another easy diagram:



Is this object moving to the right or left? It's difficult to tell, there's really not enough information, it could be to the left or right. But if we put our displacement vectors in the picture, it becomes much easier!



The vectors show us that the object is moving to the right and that it is slowing down. We said that the vectors showed us the displacement between points, but they're also an indicator of velocity.

Now to define velocity.

$$\vec{v} = \frac{\Delta \vec{r}}{\Delta \vec{t}}$$

so velocity and displacement are directly correlated – these vectors we've been drawing are proportional to velocity vectors, they may as well have been velocity vectors. This gives us an important insight into velocity if we rewrite our equation.

$$\vec{v} = \frac{\vec{r_f} - \vec{r_i}}{\Delta t} \Rightarrow \vec{r_f} - \vec{r_i} = \vec{v}\Delta t \Rightarrow \vec{r_f} = \vec{r_i} + \vec{v}\Delta t$$

So, velocity is what changes an initial position into a final position. Without a velocity, position wouldn't change.

So now that we know what velocity is, namely a vector – we can talk about some of the details:

1. Velocity is a vector ⇒ it has a magnitude and direction
2. Velocity is proportional to displacement (directed distance)
3. The standard units of velocity are meters/second (m/s)

average speed and average velocity are different!

average speed = distance traveled/total time to travel that distance

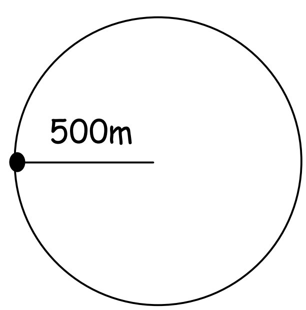
average velocity = displacement/total travel time

Let's do a quick example:

A race car travels a complete lap on a circular track of radius 500m in 50s.

(a) The average velocity of the race car is:

(1) zero, (2) 100 m/s (3) 200 m/s



First, let's think about displacement. Technically the definition is $\Delta x = x_f - x_i$. So if you take a path where your initial and final points are the same, your displacement is zero! You have not displaced yourself from your original position. Therefore, average velocity would be zero.

But average speed is another story. Speed is just distance over time. Even if you come back to the same original position, you have covered some distance. In this problem we can even calculate that distance, it's the circumference of the circle.

$$c = 2\pi r = 2(\pi)(500m) = 3140m$$

$$average\ speed = \frac{distance}{time} = \frac{3140m}{50s} = 62.8m/s$$

So to recap, the idea is that the average velocity is zero because displacement is zero (your initial and final position is the same), but the average speed is not zero because you still cover a distance.