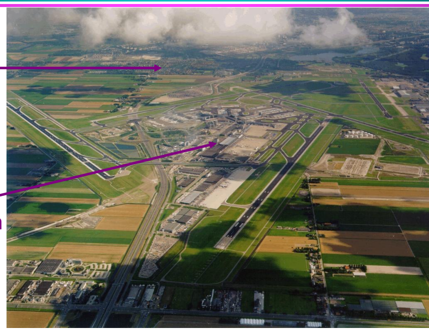
Physics 121.
Lecture 04.

This is where your instructor grew up.



Schiphol (Amsterdam Airport).

Physics 121.
Lecture 04.

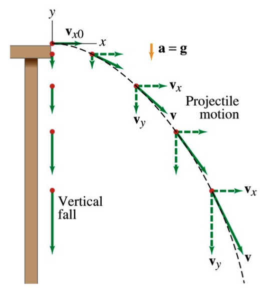
- Topics:
  - Quiz
  - Motion in two dimensions:
    - Projectile motion
    - Problem-solving strategies
    - Circular motion
    - Relative motion

Quiz.

- Let’s practice what we learned (and read).

Motion in two dimensions.

- When an object moves in two dimensions, we can consider the 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.



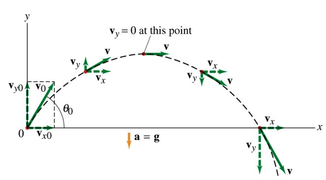
Motion in two dimensions: projectile motion.

- 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:

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

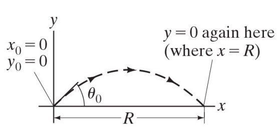
- Horizontal motion:
  - During this time interval, the distance traveled by the projectile is

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

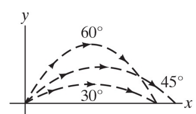


Motion in two dimensions: projectile motion.

- The equation of the range shows that the range has a maximum when $\sin(2\theta) = 1$ or $\theta = 45°$.
- The range for smaller and larger angles will be smaller.
- The difference between for example the 30° and 60° trajectories shown in the Figure is the time of flight.



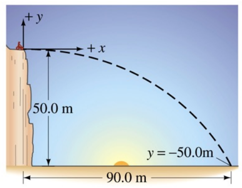
(a)



(b)

Motion in two dimensions: projectile motion: problem solving.

- Choose your coordinate system such that one of the axes is directed in the direction of the gravitational acceleration.
- Where do you choose the origin of your coordinate system?
- Determine the initial conditions (e.g. x and y components of the velocity at time $t = 0$ s, the x and y positions at time $t = 0$ s).
- Calculate the time to reach the ground, t_{gr}.
- The displacement in the horizontal direction is $v_0 t_{gr}$.



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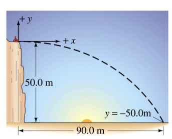
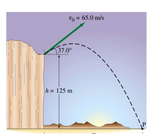
Motion in two dimensions: projectile motion: problem solving.

- The critical component of most problems is the definition of the boundary conditions (for example, the horizontal and vertical components of the position and the velocity).
- The problems may differ in what you are being asked to do (for example, determine the range of the projectile, its time of flight, etc.)





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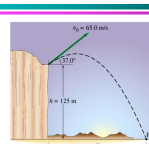
Motion in two dimensions: projectile motion: problem solving.

- In general, you should work with variables as long as you can.
- Consider the trajectory problem shown in the Figure:
  - Starting point: $x_0 = 0$ m, $y_0 = h$
  - Starting velocity: $v_{x0} = v_0\cos\theta, v_{y0} = v_0\sin\theta$
  - To calculate the range, we first calculate the time t it takes to reach the ground (this is just one-dimensional motion in the vertical direction)
  - The range R is equal to $v_{0x}t = v_{x0}\{v_{y0} + \sqrt{(v_{y0}^2+2hg)}\}/g$
  - Check your units
  - Now substitute your numbers to get a numerical answer!



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4 Minute 35 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 5 minute 35 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 4 minutes and 35 seconds.

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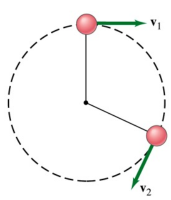
Circular motion.

- The circular motion of an object with period T can be described by the following equations:

$x(t) = r_0 \cos(2\pi\, t/T)$

$y(t) = r_0 \sin(2\pi\, t/T)$

- The motion described by these equations is motion with constant speed, $v_0 = 2\pi\, r_0/T$, in a circle of radius r_0.



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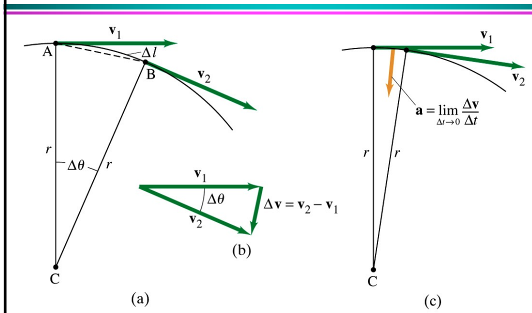
Circular motion.



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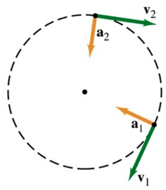
Circular motion.

- The components of the velocity and acceleration can be obtained by differentiating $x(t)$ and $y(t)$ with respect to time.
- This procedure will produce of course the same results as the graphical analysis.
- Important facts to remember:
  - The acceleration vector points towards the center of the circle.
  - The magnitude of the acceleration is v_0^2/r_0.



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Relative motion.

- The velocity of an object measured by an observer depends not only on the motion of the object, but also on the motion of the observer.
- Examples:
  - Rain appears to fall at angle θ when the observer is moving in the horizontal directions.
  - The relative velocity of two drivers going at 55 mph in the same direction is 0 mph.

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Relative motion in 1D.

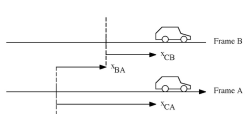
- Consider two different observers A and B looking at the same car.
- The position observations made by these observers are related in the following manner:

$$x_{CA} = x_{BA} + x_{CB}$$

- The velocities of the car according to the two observers are related as follows:

$$v_{CA} = v_{BA} + v_{CB}$$

- If V_{BA} is constant, then $a_{CA} = a_{CB}$.



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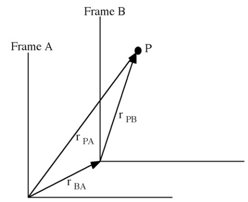
Relative motion in 2D and 3D.

- The procedures to relate the observations made by different observers in 2D or 3D is similar to what we did in 1D.
- The following relations describe the relations between the observations of observers A and B:

$$\vec{r}_{PA} = \vec{r}_{BA} + \vec{r}_{PB}$$
$$\vec{v}_{PA} = \vec{v}_{BA} + \vec{v}_{PB}$$
$$\vec{a}_{PA} = \vec{a}_{BA} + \vec{a}_{PB}$$



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Relative motion. Comments.

- An important conclusion about this discussion of relative motion is that the two observers will observe the same acceleration as long as they move with constant velocity with respect to each other.
- The laws of physics make specific predictions about the acceleration only. Thus, the laws of physics look the same for both observers, as long as they move with constant velocity with respect to each other.
- But …… the laws of physics look different to observers accelerating with respect to each other.

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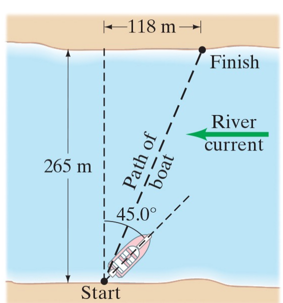
Relative motion.

- Our understanding of relative motion has many applications.
- Consider the motion of a boat across a river. Usually, the captain wants to arrive at a specific point on the other side.
- Once disconnected from the shore, the boat will move in the reference frame of the river.
- The boat will need to head into the current in order to arrive at its destination.



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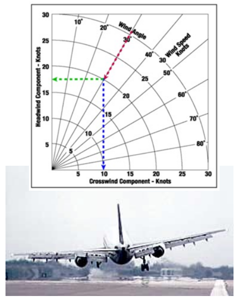
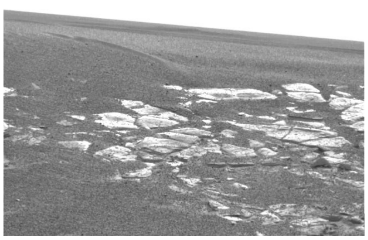
Relative motion

- Another example of relative motion is the motion of airplanes.
- Runways are fixed in the reference frame of the earth, while airplanes fly in a reference attached to the air.
- On landing the airplane needs to transition from the motion in the air to motion on the ground. This can be tricky when there are strong cross winds with respect to the runway.



Done for today.
Next week we will focus on Newton's laws.



Opportunity on Mars
Credit: Mars Exploration Rover Mission, JPL, NASA