Physics For Everyone

http://www.coloradocollege.edu/Dept/PC/RepresentativePhy/home.htm
Kinematics Problems
August 1, 2002

Section 1. Position, Velocity, and Acceleration

1.1 Harvesting the field*

A farmer sets out to harvest a field of wheat using a combine that is 25 ft. wide and has a top speed in the field of 1.8 m/s. Its acceleration can be described by the function
$a = \frac{1}{2}t$, until it reaches its top speed, when the acceleration drops rapidly to zero.

Find expressions for the acceleration, velocity, and position. At what time does the combine reach its top speed? Draw a graph of the position, velocity, and acceleration versus time, for the first 5 seconds.

1.2 An elephant lunch*

An elephant shakes a tree with her trunk in order to get down some of the seed pods for food. If the lowest branches of the tree are 3 m above the ground, how long does it take for the seed pods from these branches to fall to the ground, and how fast are they falling when they do reach the ground? (Assume no air resistance)

A baby elephant catches one of the seed pods that fell from the top of the tree (6 m high), grabbing it with her trunk at 1.5 m above the ground and stopping it 0.3 s later at 0.5 m above the ground; what was the seed pod's average acceleration between the time it was caught and the time it was stopped?

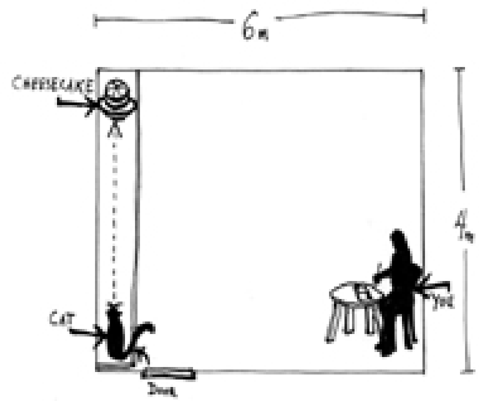
1.3 Equine Acceleration*

As a stablehand, it's your job to set the horses loose, one by one, into the pasture after the morning feed. When you release a particularly spirited chestnut quarter horse, she takes off from a standstill into a gallop, reaching top speed 6

seconds later by the time she passes a tree 15 m away. You think she might be going 25 mph judging from the comparatively familiar speeds of cars. What is her average acceleration between the gate and the tree (in m/s)?

1.4 The Cat Who Loved Cheesecake**

Your dad has just made a cheesecake and has set it on the counter in the corner of the kitchen. He is temporarily occupied, tactfully trying to get a long-winded friend off of the phone; Grymalkin, your most mischievous cat (who also happens to love cheesecake) has just entered the kitchen door and, spying the cheesecake, jumps onto the counter right by the door and begins trotting towards the cheesecake at a constant velocity of 1 m/s. If you are sitting in the opposite corner of the kitchen what does your average acceleration need to be in order to get to the cheesecake before the cat? The dimensions of the kitchen are 4 m by 6 m.



1.5 Mountain Mamas**

You get up at the crack of dawn one morning to go mountain biking with a friend. On a narrow downhill section of the trail, you let her go first, since she's eager to try out her new clipless pedals. You're riding along at a constant velocity of 4 m/s when you turn a corner and see that your friend has stopped to watch a deer in the woods; you don't want to become an entangled mess of arms, legs and bike frames, so you'd like to be able to stop before you reach her position on the trail, a little over 4 meters from you now.

If your braking acceleration on the downhill, gravel trail is 3.6 m/s^2, can you stop in time before scaring the deer away with your messy entanglement?

If your average velocity riding uphill on your mountain bike is about 5 mph, and your average velocity when riding downhill is about 16 mph, and you spend approximately 3 hours going uphill, about how long will it take you to ride down the mountain by the same route that you rode up?

1.6 The Windy City**

You would like to take the bus from a theater in downtown Chicago back home to your apartment—it's a windy, freezing cold night and all you want now is some hot cocoa. There are two different routes you could take, and you remember that one day when you did some calculations for fun, you discovered that bus A is rather shabby and can only accelerate at 2 m/s^2, whereas bus B can accelerate at 4 m/s^2. Likewise bus A's brakes are slightly worse and can only accelerate the bus at –4 m/s^2, whereas bus B's brakes can accelerate the bus at –5 m/s2. However, the average speed limit on bus A's route is 6 m/s and the average speed limit on bus B's route is only 4 m/s due to traffic. If the distance to your apartment on route A is 0.72 miles long and the distance on route B is 0.65 miles, and your apartment is the first stop for both routes, which bus actually gets you home faster to your cup of cocoa?

1.7 Life on the plains**

On the plains of Africa, the grasses, grazing animals and predators have all coevolved. Grazing animals like gazelles depend on speed and endurance to escape from predators. Big cats like cheetahs depend on their stalking skills to get close, and on rapid acceleration to catch their fleeing prey. A cheetah can accelerate from rest to 20 m/s in just 2 seconds. It is the fastest of all animals, with a top speed of 32 m/s. But it can only maintain that speed for about 300 m.

A cheetah is crouching in the grass, 50 m from a herd of gazelles when the animals begin to run. They run at 23 m/s, and can keep that up for long distances. Can the cheetah catch its prey, or will it go hungry tonight?

1.8 Speeding ticket**

Barbara commutes from Castle Rock to Colorado Springs, every day—about 45 miles straight south on the interstate, where the speed limit is 75 mph. If she drives at 85 mph, how much time does she save on her daily round trip? How does this compare to the 20 minutes she spends talking to the policeman who gives her a speeding ticket?

Section 2. Projectile Motion

2.1 Gazelles*

Gazelles are magnificent animals, native to Africa, whose ability to jump is astounding. If a gazelle leaps at and angle of 30^o above the horizontal, and travels a distance of 4 m, how long was the gazelle in the air?

2.2 Tennis Champs*

Wimbledon champs Venus and Serena Williams are relaxing with a friendly tennis game. Venus holds her tennis racket horizontally at a height of 1.5 m above the ground. She returns an incoming ball at an angle that is 5^o below the horizontal, and a speed of 10 m/s.

If Serena runs to the ball and returns it just before it hits the ground, how much time did she have to get to the ball? If she ran at half the speed of the ball, what is the maximum distance she could be from the ball, and still return it, assuming she can reach 0.8 m from where she stands? With what speed would the ball hit her racket?

2.3 Taku Tries Tennis*

On a sunny afternoon you're out playing with your dog, Taku; if you throw a tennis ball at an angle of 60 degrees above the horizontal at an initial velocity of 20 mph about how far and how fast would she have to run (in m/s) to catch the ball just before it hits the ground? Your height above ground is about 1.3 m.

2.4 Break a Leg**

Your friend is part of a dance company and is choreographing a modern dance that involves leaping off blocks that are placed around the stage. She wants to know how she should place the blocks so she can get the desired aesthetic effect. Knowing you are taking physics, she asks your advice. Derive a general formula for your friend that gives the distance from the block that a dancer will land as a function of the height of the block (h), the initial speed of the dancer (v), and the angle that the dancer leaves the block (θ).

Section 3. Vector Problems

3.1 Busy Bees*

A worker bee is ready to fly out and gather pollen, but on her way out of the hive she meets one of her fellow workers who is just returning. The incoming bee tells her, in bee-dance language, that there is a good pollen source 0.3 km southeast of the hive. However, before the outgoing bee leaves the hive, she meets another incoming bee and *she* tells her that there is also a pollen source 0.5 km due south of the hive. If the busy worker is to visit both of these pollen sources in their respective order before returning to the hive, what direction and distance will she need to fly to get from the first source to the second source? If her average velocity is about 1.5 m/s, how long will it take her to get from the first to the second source?

3.2 Heading South*

A flock of songbirds in the western U.S. is preparing to migrate south for the winter. The winds at their migration altitude are from the southwest—235^o by the compass, with wind velocities averaging at 10 kts. What direction should they actually fly in order to end up due south in Mexico? If their in-flight average velocity is 17.4 kts, how many days will it take them to travel the distance to their winter habitat there, about two thousand miles away? Assume that they can travel 17 hours out of each day. (1 kt = 1 nautical mile per hour; 1 nautical mile = 1.15 statute miles)

3.3 Mrs. Gibson*

You are one of a team of researchers interested in flight patterns and speeds of the wandering albatross. Using tracking devices you are able to determine that "Mrs Gibson" (a female wandering albatross of the Aukland island plumage—*Diomedea exulans gibsoni*—used in this particular study) is moving at 46km/h towards the east-northeast from New South Wales over the Tasman Sea with a compass heading of 77^o. From atmospheric data you know that the winds are coming at her from just north of west at 275^o at 32 km/h. How much is the wind contributing to the eastward component of her velocity? How much is the wind detracting from her northward velocity? At what heading and with what airspeed is the albatross flying?

3.4 West with the Night*

It is September of 1936, and you are the Kenyan aviatrix Beryl Markham; today you are attempting the first solo flight of the Atlantic from east to west in a specially-outfitted Vega Gull, against the prevailing winds of the North Atlantic jet stream. You don't have a radio to call for help, so you'd better do some calculations or you might not end up over land when your specialized fuel tanks run out! Your plan is to fly from London to New York, proving the potential for commercial airline routes. The initial heading from London to New York is 288 degrees. At 10,000 ft, the winds are coming at you from the southwest at 235 degrees with wind velocity of about 50 kts. If your valiant blue and silver Gull flies at its top airspeed of 163 mph, at what heading should you initially fly to correct for the wind? What will be your speed relative to the ground?

3.5 Las Hermanas de las Montañas *

Katy and her sister Rachel are climbing Mt. Denali in Alaska. Every evening they plot their position on a topo map, calculate the horizontal distance they have traveled, and record this and their elevation. This chart is shown below.

Day	**Location**	**Elevation (ft)**	**Horizontal Distance (miles)**
1	Base Camp	7200	0.0
2	Camp 1	7800	5.5
3	Camp 2	9700	2.5
4	Camp 3	11,000	2.25
5	Camp 4	14,280	2.75
6	Ridge Camp	16,200	2.0
7	High Camp	17,200	0.75
8	Summit	20,328	2.5

a) On what day did they travel the farthest? (Total horizontal plus vertical?)
b) On what day did they gain the most elevation?
c) What is the total (horizontal plus vertical) distance they traveled?
d) What is their average distance per day?
e) What is their average elevation gain per day?

3.6. Treeleaf Vector Lab

After it rains, the water that is absorbed by the ground and subsequently by a tree's root system must travel through the tree's trunk and branches to get to the leaves. Find a tree with reasonably straight branches, and find at least one leaf on this tree whose water-deliverance path you can figure out (and reach). Take a protractor and a tape measure and measure the distances and angles of each branch connecting the base of the trunk to this leaf.

What is the total upward displacement of the water that travels from just below ground surface to this leaf? What is the entire displacement? If the water in the xylem of a tree travels at 1 mm/s, how long will it take to make this journey?

3.7 3-D Gnomon Lab

We can use vectors to know more about our motion relative to the sun. How does the sun move across the sky? Where does it rise? Set? How do we explain its path? How does the path of the sun change in the sky as we move to different spots on the Earth? One way that we can answer these types of questions is by observing the shadows of objects of known heights over a period of a day. One way that this can be done is by constructing a Gnomon and observing its shadow. A Gnomon is a pillar constructed perpendicular to level ground (and the horizon). By recording the tip of the shadow of the gnomon at different times during the day, we can answer the questions that were initially posed.

The short and sweet version of this includes constructing a Gnomon on a flat surface, drawing an accurate circle around the gnomon, with the gnomon at the center of that circle. From 10AM until 2Pm record the location of the shadow and the time of that shadow. Note specifically where the shadow enters and exits the circle and record those times. Devise some coordinate system to record the positions of the each shadow so that you can carry your data around in a notebook instead of risking the loss of your data to a small squirrel or passing bicyclist.

Now with your time and location data determine a few things about the relative motion of the Earth and the sun.

a. Where is the sun in relation to earth? Plot the position of the shadow as a function of time. Where is East? West? North? South? Use the circle that you drew around the Gnomon to figure this out. Show and describe your methods.

b. What is your latitude if you know the relative angle of the sun? (this is easiest around the solstice or the equinox, but data could be found for other times as well) Conversely, if you know the latitude, at what angle is the Earth tilted relative to the sun? Compare these findings to the angle that we make with Polaris.

c. Does the sun move across the sky in a plane? Determine this by constructing vectors which point towards the sun and then taking their cross-products to determine if they are in a plne.

d. Is the velocity of the sun as it moves across the sky constant? Use again the vectors that point towards the sun and then subtract them to get velocity vectors. Are these velocity vectors the same size?

e. Can we figure out how far away the sun is? Why or why not?

f. Where does the sun rise and set? Due East-West? How would that change if we were on the equator?

Section 4: 1-D Motion

4.1 How Well is the Water?*

In rural areas of Africa, drinking water is drawn from a well by hand-cranking a bucket attached to a lowering rope. The well is 20m from the cranking axle to the water below. To lower the bucket, the hand-crank is allowed to spin freely as the bucket drops. Make a graph of acceleration vs. time, velocity vs. time, and position vs. time for this motion, assuming the cranking arm is frictionless. Label the important values in the graph such as slope, beginning and ending points, etc. Once the bucket has filled, a woman begins to crank, uniformly increasing the speed of the bucket for five seconds until it's going 0.5 m/s. She then cranks at this speed, until the bucket emerges above ground (1m left to crank). When the bucket emerges from ground she slows the bucket to a stop at a constant rate. Graph the trip of the bucket from the bottom of the well to the point where the bucket is at rest just below the cranking axle. Graph position, velocity, and acceleration vs. time. Label key transition points such as changes in acceleration and velocity on both axes.

4.2 Don't be Late for School*

In rural southern Africa, some children walk two hours to and from school each day. At the same time, they are also responsible for morning chores around the home such as sweeping the yard, washing the previous night's dishes, and feeding the goats and the chickens. From time to time these chores take longer than expected and the children will be late to school if they walk, so they run part of the way or all of the way to school. A child walks at about 4 km/hr and at this rate she gets to school in 2 hours. If she only has 1.5 hours to get to school and can run at 6.4 km/hr, what is the minimum time that she will have to run to get to school on time if both walks and runs on her journey?

4.3 Hauling Water in Southern Africa*

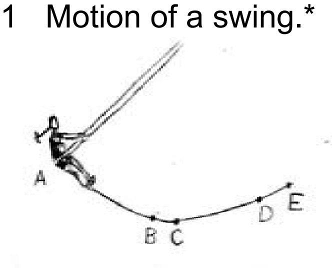
Young women in rural Zimbabwe, a country in southern Africa, must haul water over long distances so they can cook food and wash clothes, keeping their families sustained. A woman, Tsitsi, lives near a well that is 1 km due west from her house. However, Tsitsi cannot walk directly to the well because there is a rock outcropping on this route. She can take two different paths. First, she can walk slightly north of west and then turn 30 degrees to her left, walking until she reaches the well. This path is rough and she can walk 3 km/hr to the well. On the way back, with approximately 11 liters(5 gallons) of water contained in the bucket balanced on her head, she can only walk 2 km/hr. The other path is to walk ½ km straight south on the road from her village, and then follow a well-beaten path straight to the well. On this smoother path she can walk 4.5 km/hr on the way and 2.3 km/hr on the way back. Tsitsi doesn't like to go back and fourth on the same path, and she wants to minimize the time she carries water. Which path should she choose? How long will this trip take, including the 15 minutes she spends at the well filling her bucket and chatting with other women?

4.4 Quilting**

Sarah sits down to finish a quilt, 8 blocks by 6 blocks that she has pieced together for her daughter. She has made a simple patchwork top out of sky blue and yellow cotton blocks that are 25cm square. Now she wants to appliqué a ribbon on top of the patchwork. She has some red and green ribbon left over from her Christmas sewing. She must sew the red ribbon on more slowly because it easily bunches up under the foot of the sewing machine; the top speed for red is 1 cm/second. On the other hand, if she chooses green, she can sew it on at 2cm/second. She'll sew the ribbon on a continuous path, starting in the bottom right hand corner of the quilt (0,0), going straight up 8 squares to (0,8), and then following the path (-3,4), (-6,8), (-6,0), (-3,4), (0,0). The sewing machine can change speed at a rate of $1 cm/s^2$, and she must slow to a stop and restart every time she has to change directions in her pattern. How long will it take her to sew on the red ribbon? The green ribbon?

Section 5: Circular Motion

5.1 Motion of a swing.*



Watching someone on a familiar playground swing-set, we take mental snapshots of the swinger. Sketch the net acceleration and velocity vectors at position A, the highest point in the swinger's path, point B, and point C, assuming the swinger is traveling from point A to point C. What forces are at work to create this net acceleration and velocity?

5.2 Riding in cars with boys*

You are riding in a car with your friend Matt. He goes around a curve to the right, and your sunglasses slide across the dashboard to the left. Mark (who hasn't taken physics) says this is because of "centrifugal force." You have been taught in your physics class that there is no such thing as centrifugal force. Explain to Mark why your glasses slide like that.