

MENU

LAURA KINNAMAN AND G. B. RAMOS

Chapters ⇒ *Chapter 2* ⇒

CHAPTER 2

PHYSICS

Physics is all about predicting and explaining what happens. What are we trying to explain or predict? What's involved? Do those things affect each other? How do they affect each other?

Physics is all about understanding what happens in the physical world, from the extremely small (like atoms or electrons) to the extremely large (like stars and galaxies), and the everyday, human-scale objects in between. In physics, “understanding” is practical: can you predict what will happen next? Can you explain why something happens the way it does?

Like other sciences, physics answers some questions but not others. Because it deals with the physical world, physics is best at answering questions like: If you throw a basketball, will it go through the basket? If you see something unexpected on the road ahead of you, can you stop your car in time? If it's hot outside, how much energy does it take to keep your room cool? How can you connect wires and batteries to make light bulbs shine?

Physics can also tell us *why* some things happen the way they do. Why does a basketball follow a curved path through the air? Why does the car change its motion and how does it do it? Why does your room get hot if it's hot outside, and how can you cool it? How does electricity work, and why does a battery, hooked up correctly, make a light bulb shine?

Some questions that we can ask about the world make more sense to be answered by sciences other than physics—for example, kinesiology tells us how to throw a basketball most efficiently. Engineering tells us how to build a car so that it can stop quickly or how to build an air conditioner. Chemistry tells us how a battery actually works on the inside.

After all of these questions, there's a very important one we haven't addressed yet: why should you study physics? Although there are as many reasons as there are students, we can identify three common reasons.

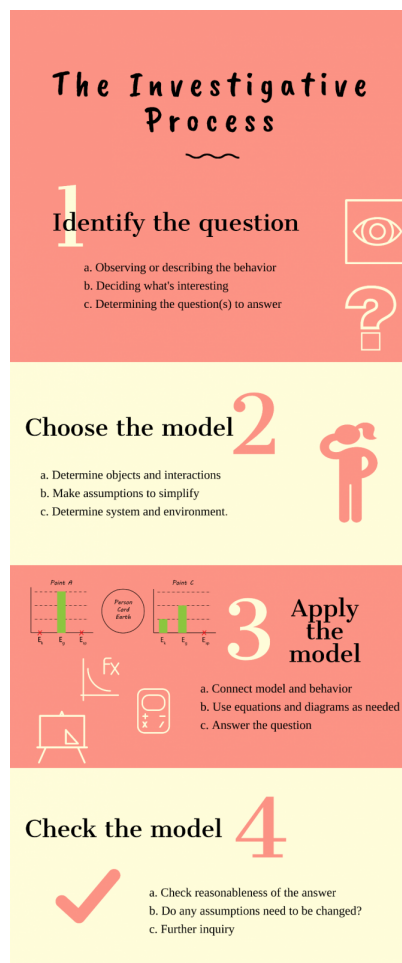


Figure 1 The investigative process that we will follow in this chapter (and throughout the book).

1. The universe is an interesting place, full of strange behavior that you want to understand. Physics lets you explain so many interesting phenomena—gravity, rainbows, or atoms. If you're curious about the physical world, physics can help you understand it.
2. You're a conscientious person, and you want to be an informed citizen. Studying physics helps you read and understand the news on topics like climate change. You can make better decisions for yourself or your community, such as if you should support nuclear power or not. Physics helps you have a better impact on the world.
3. College is a practical avenue for you, a place that helps you reach your professional goals. The actual content of what physics covers isn't as important as the way you learn to think about it. Physics helps build critical thinking skills, training your mind to address complex problems in your profession.

No matter which reason resonates most with you, you'll get that from this course.

We'll want to answer a wide range of questions and look a huge variety of messy, real-life situations. We need a useful, consistent approach to finding these answers. The approach we'll use is outlined in Figure 1, but instead of just describing it, let's see the approach in action by investigating our first situation: a bungee jumper.

THE INVESTIGATIVE PROCESS: BUNGEE JUMP EXAMPLE

As the video to the right shows, a person, attached to a bungee cord at their ankles, bravely jumps from a high bridge over roaring waters. What's interesting here? What's our question that we're going to answer? Before we go any farther in our investigation, we need to identify a clear question.

STEP 1

IDENTIFY THE QUESTION



Identifying the question involves

- ✓ Observing or describing the behavior
- ✓ Deciding what's interesting
- ✓ Determining the question(s) to answer

Let's watch the video again, this time describing the motion.



As we watch the bungee jump, we see that at the very first moment, the jumper isn't moving (they haven't jumped yet). Immediately after they jump, they're still moving slowly. As they fall, they move faster and faster. Eventually the cord snaps, and the jumper is pulled up short and they stop. After that they bounce back up and eventually fall back down again—all part of the thrill of the ride, but we'll just concentrate on that first fall.

At this point, it's useful to draw pictures of the jumper instead of watching the video over and over. Creating visual representations of motion helps us identify the important parts—where it's changing, where it's staying the same, or where it might otherwise be confusing.

It can be easier to use a dot to represent the person falling, as in the right side of Figure 2. This is called a **motion diagram** and you can watch it being generated on the video as the person's altitude is tracked through time. For more details and practice on creating motion diagrams, see the section "Chapter 1 Physics Tools" at the end of this chapter.

It can be easier to use a dot to represent the person falling, as in the right side of Figure 2. This is called a **motion diagram** and you can watch it being generated on the video as the person's altitude is tracked through time. For more details and practice on creating motion diagrams, see the section "Chapter 1 Physics Tools" at the end of this chapter.

What is interesting about the motion of the jumper? Well, why are they jumping? Do they think it's fun? Do they know it's safe? To investigate these questions as physicists, we'll have to refine them.

What aspects of the jump would contribute to it being fun? What aspects of the jump would contribute to it being safe?

What does it mean to be fun? In terms of a bungee jump, they're probably seeking the thrill of speed, and if they're jumping from a tall bridge, they want the experience to last a while. During the jump, how fast they fall will change, so we'd want to look at the fastest they go. This means our investigation question has gone from "Will it be fun?" to

1. "What's the maximum speed they travel at?"
2. "How much time do they spend falling?"

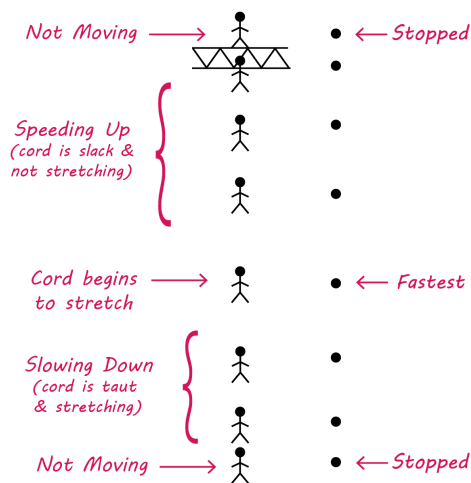


Figure 2 A sketch of the situation, showing the stick figure representation of the jumper falling. When we draw sketches, we don't try to create perfect artistic representations—we just want to include enough detail to be useful. On the right is the motion diagram representation with dots that show the same behavior.

What does it mean to be safe? Not hitting the ground would be a fantastic start, the cord shouldn't break, and they probably don't want to black out while they jump. In order to not hit the ground, the bungee cord they use should be short enough. The cord needs to be strong enough not to break. In order to not black out, their body has to change its speed slowly enough. Now our investigation question has gone from "Will it be safe?" to:

3. "When the cord stretches out, is the jumper still above the ground?"
4. "How strong does a cord need to be to not break with this jumper?"
5. "How quickly do they slow down, so that they don't black out?"

These are a lot of questions! Let's focus on just a couple of them, for now. For the fun aspect, let's look at the maximum speed (question 1). For the safety aspect, let's look at the distance they fall (question 3).

What information do we need to answer these questions? Figuring that out will be part of the next steps of the process.

STEP 2

CHOOSE THE MODEL

Choosing the model involves

- ✓ Determining objects and interactions
- ✓ Making assumptions to simplify
- ✓ Determining the system and environment

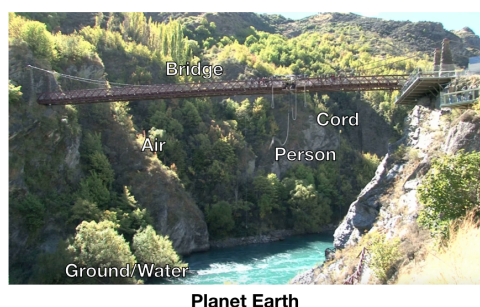


Figure 3 The Queenstown Bridge in New Zealand. A bridge crosses a gulf between two cliffs, with a river running through the bottom. The person, bungee cord,

bridge, air, ground/water, and planet Earth are all indicated.

What do we mean by a “model”?

Real-life situations are messy and complicated, so physicists create models to represent a simplified version of the situation. The models need to be easy to use but still contain enough information to reasonably explain or predict the situation. The process we use here is designed to help you identify what needs to be included and what can be left out.

First, what are all the objects involved in a bungee jump? You must have a person, a bungee cord, and a bridge. The bridge is high above the ground (and water of the river, so we'll refer to it as ground or ground/water), and there is air that surrounds the jumper. Finally, you need the entire planet Earth for the jump to take place on. (We'll dig deeper into why, but to see why that's the case for now, consider how the jump would be different if it were on the Moon instead!) Figure 3 labels all these objects.

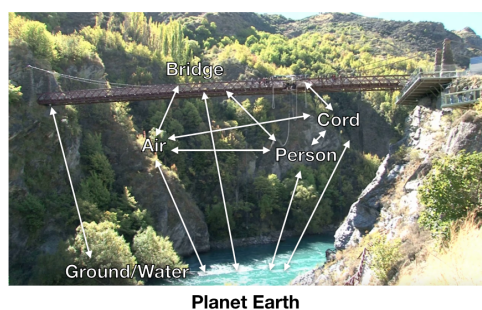


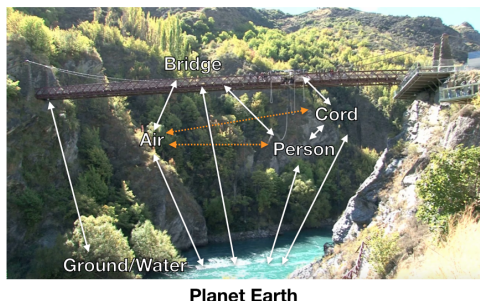
Figure 4 The interactions between all of the objects are marked by arrows. We haven't evaluated any of these interactions, so they'll start off marked in white.

How are all of these objects interacting with each other? Interactions are how objects can affect each other's motion. Often, this is by pushing or pulling on each other. All the possible interactions for the bungee jump are depicted by arrows in Figure 4.

The situation we're working with here is pretty complicated. To simplify our model, we'll need to see if there are any interactions that we can ignore because they'll have a small effect. We use **assumptions** to do so. This is somewhat risky—if you assume that the person doesn't need a bungee cord, for example, then they'll be missing a vital piece that keeps them safe. Of

course, we won't assume that, but we will have to be careful with the assumptions we *do* make (and, importantly, we'll want to revisit them at the very end to see if we did a good job).

Let's look at our interactions and determine which will have a small effect on the motion of the jumper.



AIR–PERSON AND AIR–CORD INTERACTIONS

While air definitely surrounds the person, do we think it will have a big impact on if the person speeds up or slows down? In our everyday experience, we know that air can move things around, especially on a windy day. However, if it's not very windy, then most of what it moves tends to be pretty lightweight. Does the jumper, or the cord, count as "lightweight"? It's not actually clear whether the air will have a big effect or not. Let's first try a model that leaves out the air interactions—if our results seem strange, then we could go back and change the model to include air. These two interactions are visually represented in Figure 5 as being left out of the model (in orange) but worth considering in the future (a dashed line).

Figure 5 Because we're going to leave the air–cord and air–person interactions out, we'll mark them in orange. However, since we might revisit these assumptions, we'll use a dashed line.

BRIDGE–AIR, BRIDGE–GROUND, BRIDGE–CORD, AND BRIDGE–PERSON INTERACTIONS

The air and the ground could conceivably cause the bridge to move. For example, high winds or earthquakes could cause the bridge to sway. These aren't very likely—if it's too windy, people don't bungee jump, and

earthquakes are rare. We can eliminate the bridge–air and bridge–ground interactions from the model.

Let's also assume the cord is very tightly connected to the bridge, so that it won't get loose. While the cord disconnecting from the bridge is clearly a safety concern, it's not one we're going to investigate at the moment. It's also unlikely that the attachment point moves under normal circumstances—otherwise people would find a different way to bungee jump. That means we can assume the end of the cord will be fixed in place and we no longer have to worry about this interaction.

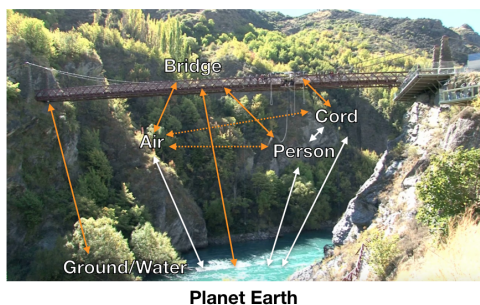


Figure 6 Because we can eliminate or don't need the interactions with the bridge, we're marking them in orange.

The bridge and the person only interact as long as the person is standing on the bridge. Once they jump, they're no longer in contact and therefore not interacting. Since the actual fall is what we care about, we can eliminate the bridge–person interaction from the model. All of the eliminated interactions are marked in orange in Figure 6.

PERSON–CORD INTERACTION

The person and the cord interact for the entire fall, although the cord's behavior changes. At the beginning, it's loose and falling with the jumper. At the bottom, the cord is stretched out. Since both the cord and the person's motion changes, this seems like an important interaction that we shouldn't eliminate.

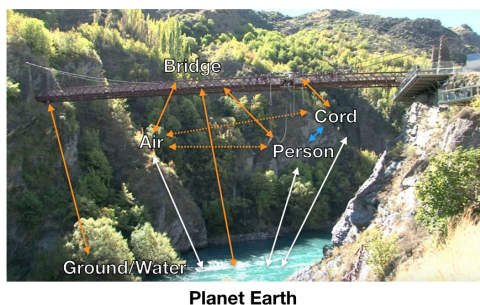


Figure 7 Since we want to keep the person–cord interaction, it's been marked in blue.

The only consideration is if the cord snaps, which it could do if stretched too far. We'll ignore this possibility because at that point they'd stop interacting, and it'd be a different situation to consider. The cord snapping might be another question to investigate later, since it is important for safety. Figure 7 shows the interaction we're keeping in the model marked in blue.

EARTH–AIR, EARTH–BRIDGE, EARTH–PERSON, AND EARTH–CORD INTERACTIONS

If the Earth–bridge interaction were strong enough, the bridge would collapse and fall toward the center of the Earth (although the surface, or ground, would get in the way first). Since the bridge is holding itself up, we can eliminate this interaction from our model.

The Earth–air interaction is interesting because if it really were absent, then the planet wouldn't have an atmosphere! However, in terms of the person doing a bungee jump, there's no effect on the jump directly from the Earth–air interaction—we've already separately accounted for the effect of the air interacting with the person. We can eliminate the Earth–air interaction as being irrelevant.

The Earth–person interaction seems to have a big impact on the motion of the person—if they were jumping on the surface of a different planet, they'd move faster or slower. This interaction depends on the person's altitude, which changes during the jump. We should keep this interaction.

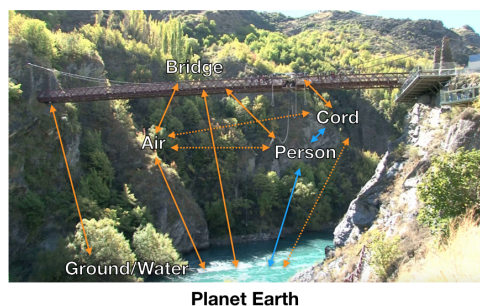


Figure 8 The Earth–person interaction is definitely important, so it's marked in blue, while the Earth–cord interaction might be worth revisiting, and is marked with an orange dashed line.

The Earth–cord interaction probably matters, especially if the cord is heavy. However, it’s not immediately clear how big of an effect it has, so we can eliminate it to keep the model simple. Once we have results from the simple model, we can consider adding this interaction back in to see if it impacts the results. If it does, we can include it to make the results more realistic, just as we decided with the cord–air and person–air interactions.

Figure 8 updates the Earth interactions, which completes the evaluation of all of the interactions for the bungee jump.

Now that we’ve identified which interactions we want to include in our model, we need to determine which objects go into the system and which are part of the environment. The **system** is the collection of objects we most care about, and any interactions between them are “internal” interactions. The **environment** contains all other objects, and interactions between the environment objects and the system objects are “external” interactions. Any interactions between objects in the environment are ignored, because they don’t affect the system objects that we care about.

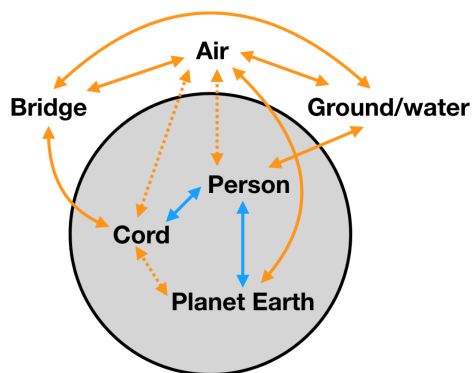


Figure 9 The interactions between all of the objects. The person, cord, and Earth are in the system, while air, ground, and bridge are in the environment.

In the bungee jump, we definitely care about explaining the motion of the person jumping, so the person will be an object in the system. We’ll also want to include a couple of other objects in the system, but not because we necessarily care about them, but because we want their interactions with the person to be internal: the Earth and the cord. You’ll see later why the distinction between internal and external interactions matters.

Everything else in the scenario will be part of the environment: the air, the bridge, and the ground. Figure 9 shows a summary of our model. Interactions we're definitely including are blue arrows, interactions we're definitely not including are orange solid arrows, and interactions we're ignoring for the moment but might want to revisit later are orange dashed arrows.

STEP 3

APPLY THE MODEL

Applying a model involves

- ✓ Connecting the model with the behavior
- ✓ Using equations and diagrams
- ✓ Answering the question

Because our model is built of the different interactions we've decided to keep, connecting the model to the behavior essentially means determining how interactions are related to different motion. One way we do that is through *energy*, which tells us how to relate interactions to values like the height of an object or the speed of an object. You'll see the concept of energy put into use for our bungee jumper: we'll first look at each interaction and its energy or change in energy, then put them all together in order to develop the model that lets us answer our questions.

EARTH–PERSON INTERACTION

The bungee jumper falls toward the Earth because of gravity. Most people are familiar with the idea of gravity as the reason why people, animals, and other objects stay on the surface of our planet—but what is gravity to a physicist?

For now, we'll say that gravity is a result of the interaction between the person and the planet Earth, because they both have mass. (We'll deal with gravity in more detail in a future chapter.) We also know that gravity is an *attractive interaction*; the object and the Earth will tend to come toward each other, rather than push each other apart.

The *gravitational energy* that an object has depends on three factors: its mass, the fact that it's near the surface of the Earth, and its height above a **reference point**, which is usually the ground. (We'll look at reference points more closely later, but for now, it's the place that we're comparing our height to.) The first two factors are because the gravitational interaction only occurs when the two objects interacting have mass—and one or both need to have planet-sized mass in order for us to measure any significant interaction! So, the object has mass, and it has to be near the Earth, which has LOTS of mass. The result of the interaction between any object and the Earth is called the *gravitational acceleration constant*, g . The value of g is 9.8 m/s^2 , as long as you are close to the surface of the Earth. If you were on the Moon, in contrast, g would be 1.6 m/s^2 instead. (We'll spend more time looking at units in Chapter 2, including what m/s^2 actually means, physically.)

Although we've limited ourselves to being near the surface of the Earth, the gravitational energy does depend on exactly how close or far you are from the surface itself (or whatever reference point you're using). Now that we've identified the three quantities that the gravitational energy depends on, it's time to see how they relate to each other:

$$\text{Gravitational Energy} = (\text{mass}) * (\text{gravitational acceleration constant}) * (\text{dis}$$

This equation tells us that if the object will have more gravitational energy if (1) its mass is bigger, (2) it's on a planet with a bigger gravitational acceleration, or (3) it's higher above the reference point.

In equation form, the relationship looks like

$$E_g = mgy$$

where E_g is the gravitational energy (measured in units called Joules, or J), m is the mass (measured in kilograms, kg), g is the gravitational acceleration constant (measured in meters per second squared, m/s^2), and y is the height above the reference point (measured in meters, m).

For our bungee jumper, m will be the mass of the person and y will be their height above the reference points we choose.

PERSON–CORD INTERACTION

Although the cord and the person are connected for the entire fall, the interaction doesn't matter during the whole jump. Before it's stretched, as the cord is slack, both the cord and person just fall—their motion is the same whether they're connected to each other or not. But, once the cord reaches its full unstretched length, its behavior changes. First, it stretches farther (as the person continues to fall), then the person stops, and then the cord contracts and pulls them back upward. The cord does this because it's made of stretchy, elastic material. Essentially, it acts like a spring.

The *spring energy* of an object interacting with a spring will depend on two factors: how stiff or loose the spring is, and how far the spring is stretched or compressed. The suspension coil on a car is a very stiff spring, but a Slinky is a very loose spring. Any spring you encounter will have its own stiffness, a value that is called the *spring constant*. When the spring constant is large, the stiff spring is hard to stretch or compress. On the other hand, when the spring constant is small, the loose spring is easy to stretch or compress.

Why does the spring energy also depend on the distance the spring is stretched or compressed? If the spring isn't compressed or stretched at all, it actually has no energy. For any spring, it's easier to stretch or compress it a small amount. It becomes harder to stretch the farther you've already stretched it. The farther a spring is stretched (or compressed), the more energy it has.

Now, we can see how these quantities relate to each other:

$$\text{Spring Energy} = \frac{(\text{spring constant}) * (\text{stretch distance})^2}{2}$$

This equation tells us that if the object will have more spring energy if (1) the spring constant is bigger or (2) the stretch (or compress) distance is bigger.

In equation form, the relationship looks like

$$E_s = \frac{ks^2}{2} \quad (1)$$

where E_s is the spring energy (measured in Joules, J), k is the spring constant (measured in Newtons per meter, or N/m), and s is the stretch/compress distance from the reference point (measured in meters, m).

For our bungee jumper, k is the spring constant of the bungee cord and s might be more appropriately called y_s , since that's how we've labeled the vertical stretch of the spring. That means, applied to our situation, the equation would look like

$$E_s = \frac{k(y_s)^2}{2}$$

The same equation can look slightly different depend on the situation you're applying it to. Equation (1) is the generic version that you can always use.

KINETIC ENERGY

Not all energies are associated with interactions. When an object is moving, it has more energy than when it's not moving. This energy associated with movement is called *kinetic energy*. Kinetic energy depends on two factors: how much mass the object has, and how fast it's moving. Mass matters because it's harder to put something heavy into motion and easier to put something light into motion.

Since kinetic energy is the energy of motion, it makes sense for speed to matter.

The relationship between these factors is

$$\text{Kinetic Energy} = \frac{(\text{mass}) * (\text{speed})^2}{2}$$

This equation tells us that the object will have more kinetic energy if it (1) has more mass or (2) has a larger speed.

In equation form, the relationship looks like

$$E_k = \frac{mv^2}{2} \quad (2)$$

where E_k is the kinetic energy (measured in J), m is the mass (measured in kg), and v is the speed (measured in meters per second, or m/s).

Now that you've seen how interactions and motion relate to different energies, it's time to use those energies to investigate our bungee jumper. If you watch the video of the jumper's motion, you can see that at different times, the jumper is either high above the ground, attached to a stretched cord, and/or moving fast. Let's first sketch some of these moments to use as reference (see Figure 10). Important points to capture in a sketch might be when the jumper is standing on the bridge, when they're falling (with a loose cord), when the cord is extended but not yet stretching, and when the cord is stretched as far as it can be. These moments are depicted in Figure 11.

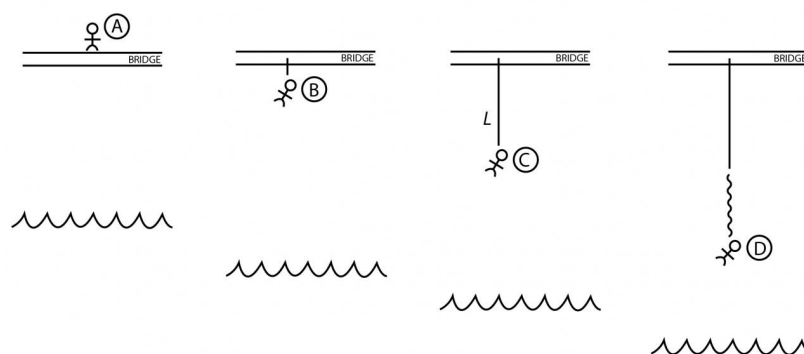


Figure 10 the jumper stands on the bridge, ready to jump; (B) the jumper is falling down, but the cord isn't stretched yet; (C) the cord is its full unstretched length; (D) the jumper is at the very bottom of their jump, with the cord stretched.

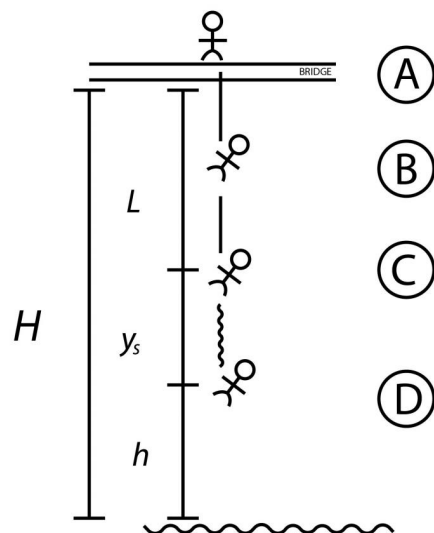


Figure 11 Important distances for the bungee jumper are labeled. The total height of the bridge above the water is H ; the unstretched length of the cord is L ; the length the cord stretches is y_s ; the remaining height above the water is h .

A great way to connect those positions and speeds to energies is with **LOL diagrams**. LOL diagrams are named after their shape, and they're very useful as a tool for organizing all of the information you have and setting up your model of the system. While there are underlying physics principles at work with LOL diagrams, for now we'll just show you how they function. (Later, we'll dig into *why* they work!)

Before we create our LOL diagrams, we should revisit the questions we're trying to answer. First, in our question about how fun the bungee jump is, we're trying to answer the question of "What's the maximum speed they travel at?" Second, for our question about how safe the jump is, we're trying to answer the question of "When the cord stretches out, is the jumper still above the ground?" Let's answer these one at a time, demonstrating how the LOL diagrams are constructed.

“WHAT’S THE MAXIMUM SPEED THEY TRAVEL AT?”

LOL STEP 1

CHOOSING THE SYSTEM

The first step in creating an LOL diagram is identifying your system. We’ve already done this during our process of investigating the interactions, so we will use the person, cord, and planet Earth as our system. This choice ensures that the gravitational interaction between the person and planet, plus spring interaction between the person and cord, will be internal interactions.

It’s important to note that only objects can be part of a system, not interactions—you can’t, for example, include “gravity” as part of your system.

Write all of the objects that you’ve chosen to be the system inside the O of the LOL diagram, as shown in Figure 12.

LOL STEP 2

IDENTIFYING COMPARISON POINTS AND REFERENCE POINT

The second step in creating the LOL diagram is determining what happens in each L. The LOL diagram lets you compare what’s happening at any two points in the motion of an object in the system—the first point in the first L, and the second point in the second L. For our bungee jumper, that means we

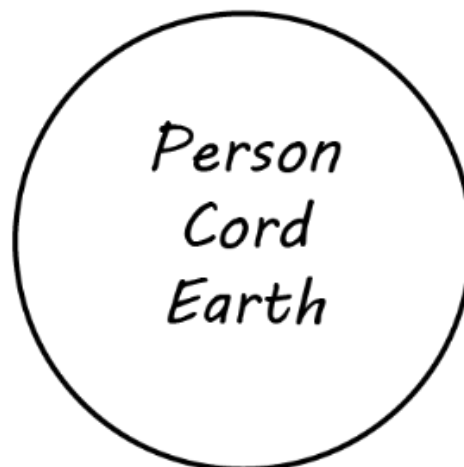


Figure 12 Our chosen system for the bungee jump scenario

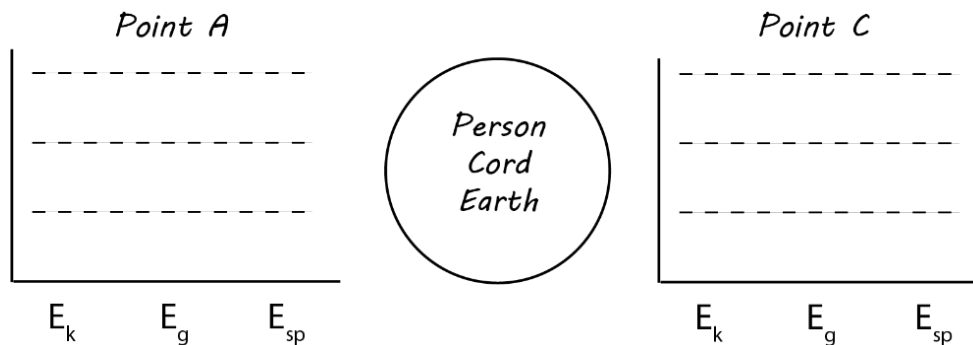
could compare Point A (sketch A), when the person is still standing on the bridge, to Point B (sketch B), when they're falling. Or, we could compare A to Point C (sketch C), where the cord has just gotten extended but hasn't stretched yet. We could compare A to Point D (sketch D), where the cord is stretched. We could compare C to D instead, or any other combination of points—we decide which points to compare based on what we want to know about the jumper's motion. Usually, the points you choose as “interesting” and worth comparing fall into one or more of these categories:

- Extremes of the motion (such as earliest in time, highest up, farthest down, or moving fastest)
- Moments when the interactions change (such as when the cord goes from not stretched to being stretched)
- Other moments that directly relate to a question you're trying to answer

For our question, we care about the fastest that the jumper goes. That's an extreme of the motion, and one of the points we will include in our comparison. Where does the jumper go the fastest? If we look at our motion diagram, we can see that it's at point C—where the person had time to go faster and faster as they fall, but not yet been slowed by the stretching cord.

Since the question doesn't refer to any other specific point, we have the freedom to choose our other comparison point. Point A, where the jumper isn't moving yet, is a simple point so it's a reasonable choice (but you could use other points if you wanted to!).

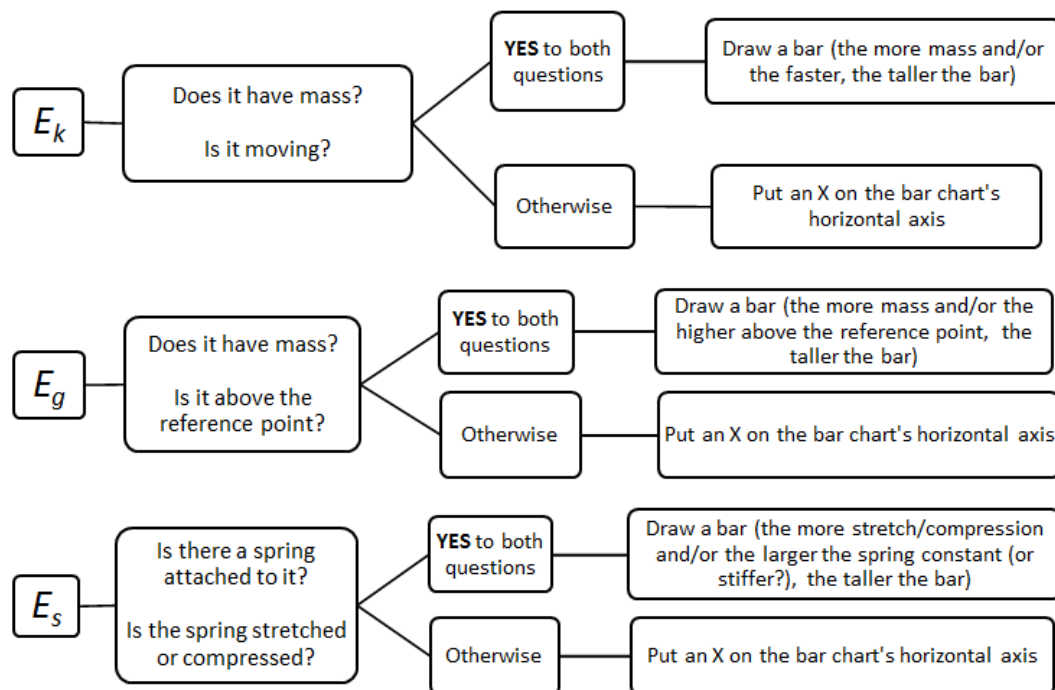
We need to have a reference point before we can answer energy questions. The simplest choice is to put the reference point at the lowest position the object can go—for our jumper, that will be point D. That means, when we look at the heights at points A or C, we'll be comparing them to point D's position.



LOL STEP 3

ASKING AND ANSWERING ENERGY QUESTIONS

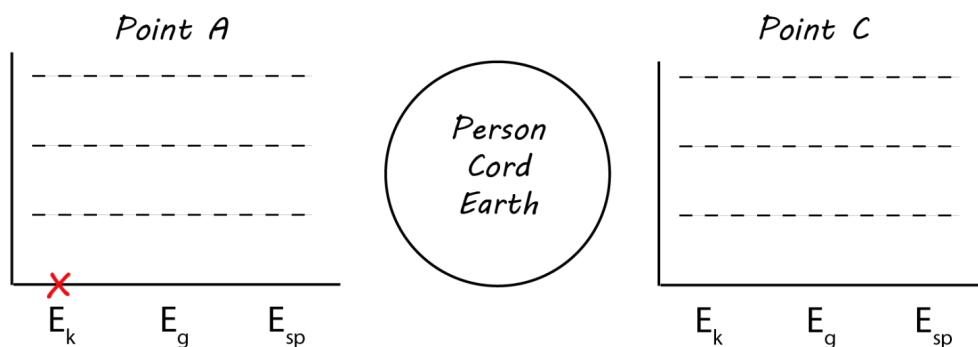
For each point, we ask ourselves the following set of questions.



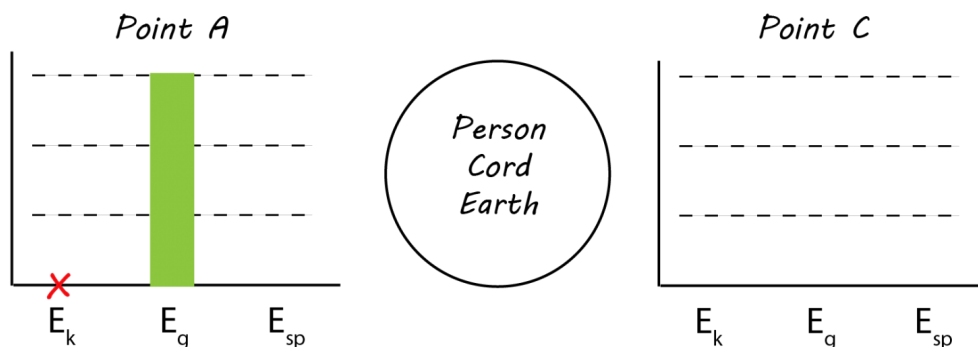
All of the information about point A will go into the first L and all of the information about point C will go into the second L.

At point A, the bungee jumper is standing on the bridge, just about to fall. We ask if the jumper has mass, and they do. However, they are not yet moving. Since we didn't answer YES to both questions, we put an X on the horizontal

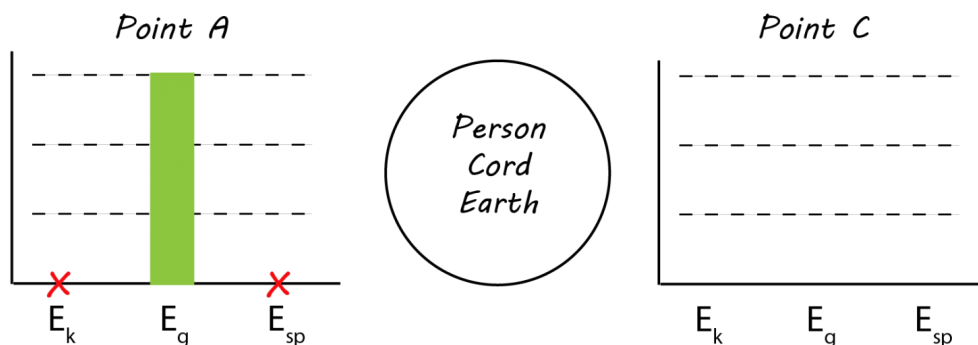
axis of the first L for the kinetic energy E_k . In other words, the bungee jumper does not have kinetic energy.



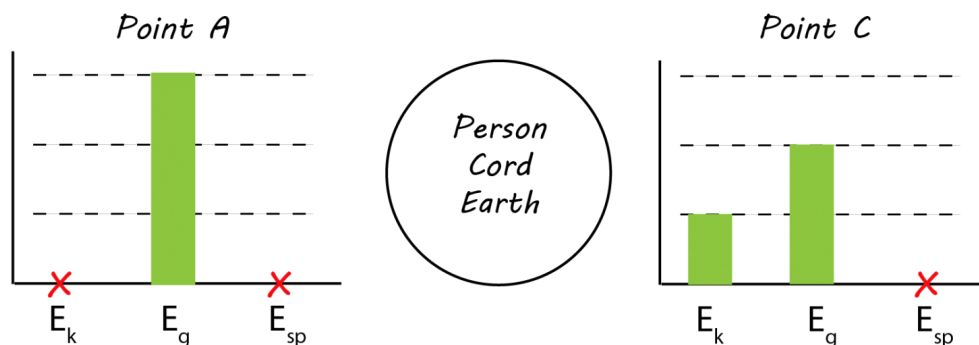
We know the person has mass, so we move onto the second question for E_g . Are they above the reference point? Because the reference point is below them at point D, the answer is YES. We'll include a bar above E_g on the horizontal axis to represent the amount of gravitational energy the jumper has at point A, standing on the bridge.



Lastly, we ask if the person is attached to a spring. They are, because the cord acts like a spring. However, the answer to the second question is NO, since at point A the cord is not stretched (or compressed). We place an X on the horizontal axis to represent that the person has no spring energy at point A.



Now we repeat this process for point C. At point C, the person is falling and the cord is extended, but it hasn't yet pulled tight. For E_k , the person has mass and they are moving, so we draw a bar on the axis of the second L to represent their kinetic energy at point C. For E_g , the person has mass, and they are above the reference point at D. Since the answer is YES, we mark a bar on the axis at E_g to represent that the person has gravitational energy (you can draw it shorter than the bar at point A, to show that it has a smaller amount of gravitational energy, since it's not as high up). For E_s , the person is attached to the cord, but the cord is not stretched or compressed. We mark an X at E_s to show they have zero spring energy.



Physically, what's happening here is that the person is converting some of their large amount of gravitational energy at point A into kinetic energy at point C, but some of it stays gravitational.

LOL STEP 4

DETERMINING TRANSFERS OF ENERGY

In this scenario, the first L represents the total amount of energy that the system has at point A, and the second L represents the total amount of energy that the system has at point C. These amounts of energy could be the same as each other, or they could be different—depending on if or how the system's objects interact with the environment's objects. For the bungee jumper model we've developed, there are no interactions with objects in the environment, so for now we'll skip this step. Just be aware that it is possible for the system

to lose energy by transferring it to the environment, or for the environment to pump more energy into the system. You'll see examples of both in later sections.

LOL STEP 5

WRITE THE ENERGY EQUATION

Now that the LOL diagram has been constructed, it's time to use it. We write our energy equation based on the diagram by adding up all of the energies in the first L, then adding or subtracting any transfers of energy at the O, and setting it equal to all of the energies at the second L. (As a shortcut, remember "L + O = L")

For the bungee jumper, this equation ends up looking like

$$\begin{array}{ccc} \text{At point A} & & \text{At point C} \\ E_g & = & E_k + E_g \end{array}$$

The gravitational energy is $E_g = mgy$, where m is the mass of the jumper, g is the gravitational acceleration constant 9.8 m/s^2 , and y is the height above the reference point. To know what values of height to use at each point, it's useful to look at Figure 11. At point A, the height above D is $L + y_s$, since L is the length of the cord and y_s is the length that the cord stretches. At point C, the height above D is just y_s .

The kinetic energy is $E_k = mv^2/2$, where v is the speed of the jumper. Once you substitute the equations for each type of energy, you have

$$\begin{array}{ccc} \text{At point A} & & \text{At point C} \\ mg(L + y_s) & = & \frac{mv^2}{2} + mgy_s \end{array}$$

Now we're ready to answer the question of how fast the jumper goes! This equation includes the variables m (mass of the jumper) and L (the length of the unstretched cord), both of which we know the values of. The jumper's mass is $m = 75$ kg and the length of the unstretched cord which is $L = 30$ m. The value of g is 9.8 m/s^2 , a constant (when on the surface of the Earth). We don't know y_s , which is how far the cord stretches, or v , the speed of the jumper at point C. The speed is what we're looking for, but before we find it, we have to deal with y_s .

If you multiply the mg through both terms in the parentheses, you'll get

$$gL + mgy_s = \frac{mv^2}{2} + mgy_s$$

Then, you can subtract mgy_s from both sides,

$$mgL + mgy_s - mgy_s = \frac{mv^2}{2} + mgy_s - mgy_s$$

In order to get

$$mgL = \frac{mv^2}{2}$$

The only variable left is v , the speed we're looking for. Solving the equation for v looks like:

$$\left(\frac{2}{m}\right) \cancel{m}gL = \left(\frac{\cancel{2}}{\cancel{m}}\right) \frac{\cancel{m}v^2}{\cancel{2}} \quad (\text{divide both sides by } m \text{ and multiply by } 2 \text{ to isolate } v^2 \text{ on the right side})$$

$$\sqrt{2gL} = \sqrt{v^2} \quad (\text{take the square root of both sides to get } v \text{ instead of } v^2)$$

$$v = \sqrt{2gL} \quad (\text{flip it around so that } v \text{ is on the left side})$$

Plugging in values gives

$$v = \sqrt{2gL} = \sqrt{2(9.8\text{m/s}^2)(30\text{m})} = 24\text{m/s}$$

That answers our question . . . but how good of an answer is it?

STEP 4

CHECK THE MODEL

Checking the model includes

- ✓ Checking reasonableness of the answer
- ✓ Do any assumptions need to be changed?
- ✓ Further inquiry

We have an answer to the question of the fastest the jumper travels, but we need to make sure it's an answer that makes sense. Our value is 24 m/s, but most people raised in the United States don't have a good sense of how fast speeds are in m/s. Our first step should be to convert the answer into miles per hour, a set of units we can more easily evaluate:

$$\left(\frac{24\text{ m}}{1\text{ s}}\right) \left(\frac{1\text{ mile}}{1609\text{ m}}\right) \left(\frac{3600\text{ s}}{1\text{ hour}}\right) = 54\text{mph} \text{ (See Physics Tools for unit conversion explanation)}$$

Fifty-four miles per hour is highway driving speed! That seems pretty fast, but the fastest bungee jump in the world (from the 233 m tall Macau Tower in China) gets jumpers up to 124 mph [1]. Our jump is much shorter than the Macau Tower, and should be slower as well.

Now is also the time to reevaluate our assumptions. Are there any that should be changed, to get a better answer? Of the interactions we ignored, the person–air interaction seems like it could change the speed of the person as they jump. The person–air interaction is called “air resistance” and occurs because as the person moves through the air, the individual air molecules bounce off of the person and block their motion. Air resistance would slow the person down (imagine an extreme case, where the bungee jumper was wearing a parachute to increase the amount of air resistance. They might not speed up at all as they fell!) Our jumper could also be slowed by the air interaction, and in a later chapter, we’ll see how to make that change to our energy model.

STEP 3 (REVISITED)

Since we have another question to answer, we’ll jump back to Step 3 of the overall process, where we apply the model.

“WHEN THE CORD STRETCHES OUT, IS THE JUMPER STILL ABOVE THE GROUND?”

The second question we’re asking is about safety. No one wants to jump with a bungee cord that’s too long or stretches too far. The point where the jumper is closest to the ground is point D. We’re now looking at a new point during the motion of the jump, so we need to construct a new LOL diagram.

LOL STEP 1

CHOOSING THE SYSTEM

We've already chosen a system and it still includes all of the objects we need (person, planet Earth, and cord), so there's no reason to change it for this question.

LOL STEP 2

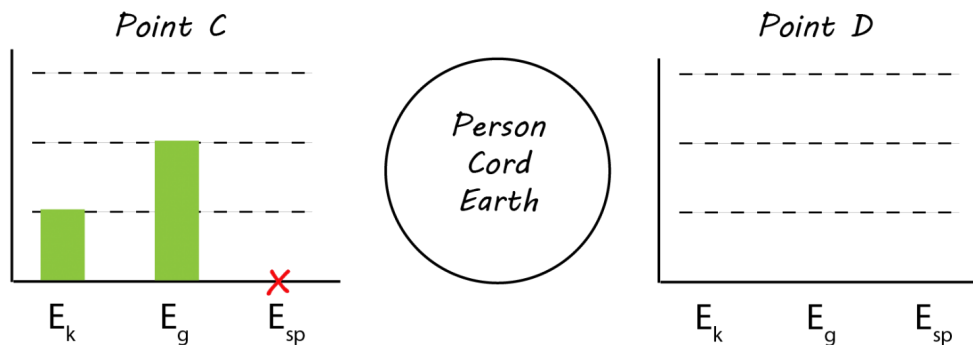
IDENTIFYING COMPARISON POINTS AND REFERENCE POINT

We know we need point D, since that's the point closest to—but hopefully not touching—the ground. We can choose any other point for our second comparison, so let's pick point C, in order to compare when the cord is stretched to when it is extended but not stretched.

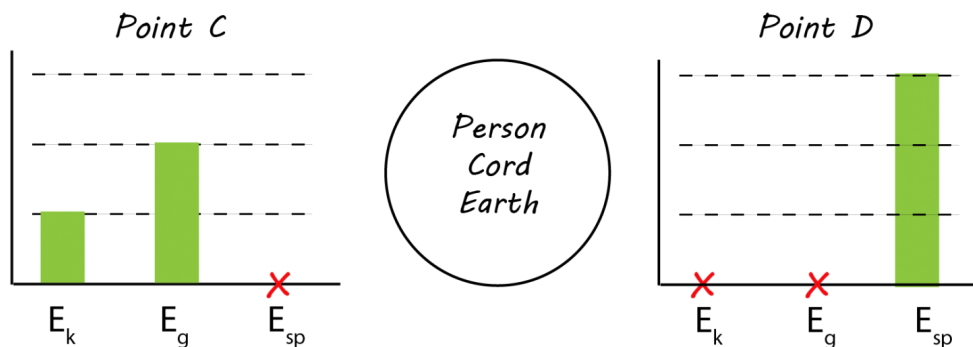
LOL STEP 3

ASKING AND ANSWERING ENERGY QUESTIONS

For the first L, we'll look at point C. At point C, the jumper is moving the fastest that they travel, and they're a distance above D equal to how far the cord stretches. So, the answers to the E_k question are YES, and we mark a bar on the L. The answers to the E_g question are also YES, since point C is above the reference. However, at point C, the cord is unstretched, so the answer to “is the string stretched or compressed?” is NO, and we mark an X at E_s . (These answers might seem familiar—in fact, because we used the same reference point, the energies at C will be the same and you could have just copied the L from the other diagram!)



For the second L, we're looking at point D: the bungee cord has extended as far as it can go, and it's the point of the motion right before the jumper is yanked back upward. At that point, they aren't moving. The answer to the "is it moving?" question is NO, so we mark an X at E_k . The answer to "is it above the reference point?" is also NO, since we moved the reference point to D, so we also mark an X at E_g . However, the answers to the spring energy questions are YES, so we put a bar at E_s .



LOL STEP 4

DETERMINING TRANSFERS OF ENERGY

Once again, for the moment we're ignoring any interactions of the objects in the system with objects in the environment, which means there aren't any transfers of energy to include.

LOL STEP 5

WRITE THE ENERGY EQUATION

Adding all of the energies in the first L to the transfers in the O and setting equal to the energies in the second L gives:

$$\begin{array}{ccc} \text{At point C} & & \text{At point D} \\ E_k + E_g & = & E_s \end{array}$$

Now, we replace each energy type with its equation applied to this situation to get

$$\begin{array}{ccc} \text{At point C} & & \text{At point D} \\ \frac{mv^2}{2} + mgy & = & \frac{k(y_s)^2}{2} \end{array}$$

Although we've just copied in the equations, it's important to check what each variable actually means in the context of this situation. For example, for the gravitational energy equation, y represents how high above the reference point the person is. Here, that's the difference in height between point C and point D, or, in other words, how far the cord stretches. But for the spring energy equation, y_s represents how far a spring stretches or compresses—which will be the same as the distance y ! That means we can rewrite our energy model as

$$\frac{mv^2}{2} + mgy_s = \frac{k(y_s)^2}{2} \quad (3)$$

Before we jump into solving this equation, we need to know what we're solving for. If we consider our question, "When the cord stretches out, will the jumper still be above the ground?", it seems like we should be trying to find the height of the jumper above the ground when they're at point D. That variable doesn't show up in our energy equation! Here is where the diagram we drew of the situation really helps, because it shows that the height of the

bridge is the same total distance as the length of the cord, the distance the cord stretches, and the height of the person above the ground. We can write that as an equation:

$$H = L + y_s + h$$

where H is the height of the bridge, L is the length of the cord, y_s is the distance the cord stretches, and h is the distance we want, the height of the person above the ground. We know H and L , so if we knew y_s , we could then find h . We can find y_s using our energy equation.

The first step is taking a look at our equation. We want to find y_s , and it shows up in two places, with mgy and with $\frac{k(y_s)^2}{2}$. Since one of these y_s 's is squared, that means we'll be using the quadratic equation to solve for y_s . The quadratic equation says that if our equation is in the form of

$$A(y_s)^2 + By_s + C = 0 \quad (4)$$

then, there are two possible answers determined by selecting the + or - sign in the following formula:

$$y_s = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (5)$$

We need to set up our energy equation given by Equation (3) to look like Equation (4) in order to know which values plug into where in Equation (5). We'll do that by subtracting each term in the left side over to the right side:

$$\begin{aligned} \frac{mv^2}{2} + mgy_s &= \frac{k(y_s)^2}{2} \\ 0 &= \frac{k(y_s)^2}{2} - mgy_s - \frac{mv^2}{2} \end{aligned}$$

Our values are $k = 3,000 \text{ N/m}$, $m = 75 \text{ kg}$, $g = 9.8 \text{ m/s}^2$, and $v = 24 \text{ m/s}$; plugging these in turns our energy equation into

$$0 = (1500 \text{ N/m})(y_s)^2 - (735 \text{ J/m})y_s - 21600 \text{ J}$$

If we match this to the quadratic equation, we get $A = 1,500$, $B = -735$, and $C = -21,600$. Using those values in the solution to the quadratic equation gives these two numerical answers:

$$y_s = \frac{-(-735) + \sqrt{(-735)^2 - 4(1500)(-21600)}}{2(1500)} = 4.0 \text{ m}$$

and

$$y_s = \frac{-(-735) - \sqrt{(-735)^2 - 4(1500)(-21600)}}{2(1500)} = -3 \text{ m}$$

A negative result doesn't make any sense here, since we're finding how far the cord stretches. Our answer should be 4.0 m.

We can now answer the question! Since the height of the bridge above the water is $H = 42 \text{ m}$, the length of the cord is 30 m, and the cord stretches by 4.0 m, the total distance between the jumper and ground is $42 \text{ m} - 30 \text{ m} - 4 \text{ m} = 8 \text{ m}$.

STEP 4 (REVISITED)

First, let's do a unit conversion to make sure the answer makes physical sense.

$$8 \text{ m} \left(\frac{3.28 \text{ ft}}{1 \text{ m}} \right) = 26 \text{ ft}$$

Interactive prediction: have students predict if the cord stretches farther or less far and give reasoning

Let's make up a lower value for the jumper's speed and see how it affects the cord stretch distance. If they traveled at 20 m/s instead of 24 m/s, what is the new cord stretch distance? It's a good idea here to practice the calculation, then compare to our answer:

The new stretch distance is only 3.4 m, shorter than before, which means the jumper ends up even higher above the ground. It looks like the effect of the air interaction is to make this aspect of the jump even safer.

We've now used the investigative process from Figure 1 to answer two different questions about the motion of a bungee jumper. This same process will be used throughout the book to answer questions about a wide variety of topics! Some of the details will change (especially Step 3, where we apply the model) but the overall process will become very familiar, and can be used even beyond the confines of this physics course. We'll also revisit the bungee jumper later to answer some lingering questions, such as how do we include the effect of air resistance and does the mass of the cord matter.

REFERENCES

1. Macau Tower: Tower Adventure (2020, February 13). Retrieved from <https://www.macautower.com.mo/tower-adventure/>
(<https://www.macautower.com.mo/tower-adventure/>)
-

CHAPTER 2: QUIZ

Availability Start Date:

Mar 11, 2020 @ 02:28 AM MST

Your Status:

BEGIN YOUR ATTEMPT

(<https://citruscollege.grlcontent.com/launch-assessment/4596278?page-id=webcom-view-page%2F141%2F10564%2F10561%3Fpage-id%3D595529>)

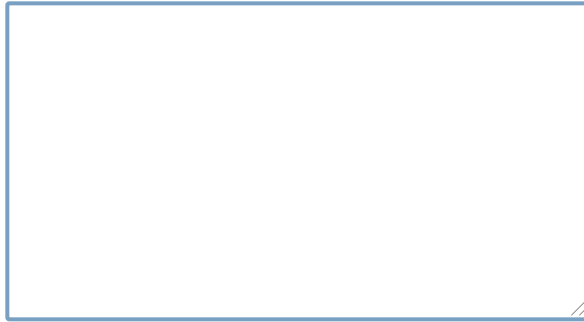
CHAPTER 2 PRACTICE QUESTIONS

Answer these following questions for practice

- * A child sits on a swing, and you give them a push from behind so that they begin to move. What are all of the objects that the child interacts with during this push?

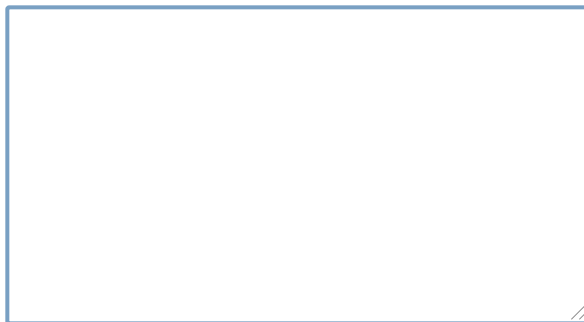


- * Of all of the interactions the child on the swing experiences, which ones could you safely ignore if you wanted to investigate how high up they would swing? Give a reason why each assumption is justified.



- * Two students are discussing sports.

Chandra: “The motion diagram for throwing a ball is always going to be the same as the diagram for kicking a ball, because they’re both flying



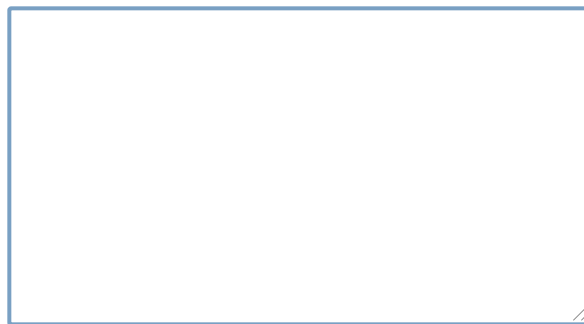
through the air.
They're both
curved."

Jace: "But throwing
and kicking are
different, and I
think the motions
through the air will
be different, too.
Even if the kicked
ball's motion is
curved, the throw
could be straight."

What are the
assumptions that
each student is
making about the
motion of the
thrown ball vs the
kicked ball?

Describe a scenario
where Chandra is
correct. Describe a
scenario where Jace
is correct.

- * A skateboarder
moves in a skate
park. Using the
LOL diagram of its
energies, describe a
possible motion of
the skateboarder.



- * What, if anything, is wrong with this energy model for the skateboarder?

$$mv_i^2 = \frac{mv_f^2}{2} + mgh_f$$

If it is wrong, fix it.

SUBMIT

PREVIOUS

([HTTPS://CITRUSCOLLEGE.GRLCONTENT.COM/WEBCOM-VIEW-PAGE/141/10564/10561?PAGE-ID=601257](https://citruscollege.grlcontent.com/webcom-view-page/141/10564/10561?page-id=601257))

NEXT ([HTTPS://CITRUSCOLLEGE.GRLCONTENT.COM/WEBCOM-VIEW-PAGE/141/10564/10561?PAGE-ID=595525](https://citruscollege.grlcontent.com/webcom-view-page/141/10564/10561?page-id=595525))

For questions or concerns regarding this online publication, please contact **web support** (<https://citruscollege.grlcontent.com/eform/submit/support-form>).

Having troubles viewing something on the page, make sure you have the correct **plug-ins** (<https://citruscollege.grlcontent.com/systemRequirements>).

GRLContent™ is a trademark of Great River Learning. All rights reserved. © 2002-2020.

View the Great River Learning

Privacy Statement (<https://citruscollege.grlcontent.com/showPrivacyPolicy>) | **Terms and Conditions** (<https://citruscollege.grlcontent.com/termsOfUsePage>).