Science-Physics-Perimeter- Visualising energy transcript  
   
(Duration 24 minutes 20 seconds)

(soft music)

This workshop has been developed in collaboration with the Perimeter Institute. Starting as an idea in 1999 and founded in 2000, the Perimeter Institute for Theoretical Physics is a world class physics institute. Perimeter is located in Waterloo, Ontario, Canada. In addition to excellence in research, Perimeter values outreach and helping teachers, help students to learn better. It is part of this process that has resulted in this video. We're very fortunate that they have developed this workshop especially for New South Wales teachers. And I hope that you and your students gain a deeper understanding of energy by participating in it.

Welcome to a Perimeter Institute video workshop, Visualising energy for deeper student learning. This video is being developed to support teacher's implementation of their curriculum in New South Wales. We will be presenting this video as if we were doing a workshop with teachers in person. There will be places where you are instructed to pause the video and attempt to answer the questions. We will be providing solutions within the video. So that you can check your answers, after you've tried the questions. This video, will deal with two resources from the Perimeter Institute. One of them is a grade 11 resource for the Ontario Canada curriculum called "A Deeper Understanding of Energy." And the other is a resource that is being released in September of 2020 called "Tools for Teaching Science." All of the Perimeter resources are available for free for teachers around the world. You can download your copy at the address that's given here. [Slide reads: <https://resources.perimeterinstitute.ca/> ] It will be repeated at the end of the session. For the teachers, you will get a PDF version of the whole resource, including teaching notes and advice and tips and how to use our materials. As well as Word editable student facing pages so that you can adapt them particularly to your teaching situation.

In this video, we are going to look at five different things. We're going to talk about what are multiple representations and why we use them. We're going to talk about something we're very familiar with doing it in terms of forces and interaction diagrams or free-body diagrams. We'll apply them to the idea of energy. And this could be something which is new to you. And we'll be using things called energy flow diagrams and work-energy bar charts. And then we're going to look at applying these multiple representations to the photoelectric effect.

So, to begin, what are multiple representations? In the science classroom we're very familiar with graphs and equations and vector addition diagrams. Some of the things that we might be less comfortable with are things like wall murals, posters. anchor charts, or even interpretive dance. The photo on the bottom right is from a group of PhD students using interpretive dance to communicate their PhD thesis topics. Why should we be using multiple representations? The research has shown that when students need to translate their understanding from one representation to another, that process helps them to deepen their understanding. Each representation has a strength that the other representations don't have. For those teachers who have the foundation that students need to learn in their own way, multiple representations allow every student an entry point into a particular topic. This is something that we know because we know that a graph more easily shows a trend in data than the data table does. But the data table more clearly shows the precision with which the experiment was performed.

When we apply multiple representations to forces, we're very familiar with things like interaction diagrams. Where we have a book on a table. And we have the book exerting a force on the table, and the table exerting a force on the book that the Earth exerts a force of gravity on the table. And the table exerts to force the gravity on the Earth. And those gravitational forces also exist between the book and the Earth. So that's often a first step that we do with student before we get to the idea of a free-body diagram. And with a free-body diagram, we pick one of the objects from our interaction diagram. And we draw the significant forces acting on it. So, the free-body diagram on the right has the two significant forces acting on the book. The force of the table up called the normal force. And the force of gravity acting down.

Here's an example of a context that has, dealing with conservation of energy in the melting of ice cubes. An illustration of an energy flow diagram and an illustration of the work-energy bar chart. Don't get bogged down in the details here. This is taken from the resource "A Deeper Understanding of Energy." So, you can go there later. It just sets the context of where we will be going and how versatile this representation is. One of the things that we have learned as educators getting prepared for teaching energy, we often as teachers, can read a context and we right away know whether we want the students to be using a conservation of energy approach or a work-energy theorem approach. Unfortunately, this is what our students see. They see conflicting signs. They see conflicting evidence. They know that they understand each bit but they don't know how to put the bits together. A quick advertisement for something that's coming at the end of this presentation is looking at the photoelectric effect. This sign, we're going to come back to this at the end.

Situation one, we have a hand and we're going to drop the ball. We would often describe this as the ball at the top has potential energy. When we let go, that potential energy becomes kinetic energy as the ball falls. And that is the normal language that we have often marked as correct. The first time I attended this workshop, when I was challenged on that language, and I'll give you the revised language here, the gravitational energy stored in the gravitational interaction of the ball and the earth, is transferred to kinetic energy. With the idea being that the energy is not stored in the balls motion, relative to Earth's surface, I realised that there were some really interesting subtleties in this whole idea. The challenge is that, we know that there is energy because we can observe a change. In the absence of change, we know nothing about the presence of energy. Okay, so here's the ball. We're dropping the ball. We have stored energy in the gravitational interaction of the ball and the Earth. And we know that we have some kinetic energy because we are seeing motion. For more ideas around how fields store energy, Perimeter has a fields resource, and it explores in-depth ideas around field storing energy, how we can tell when a field of storing energy. I invite you to download and look at that resource as well as.

An energy flow diagram starts with a circle. The circle is your system. And inside the system, we put the things that interact. It turns out that this is, one of the most important steps that we as teachers do in our heads as we prepare to respond to a question or solve a problem. And it is the steps that we most often miss sharing with our students. They are left guessing as to what the system is. And because they're guessing, we see that in their uncertainty about whether it's work-energy or conservation of energy. And that falls out completely for free once we've defined our system. So, let's see how that works. Inside the system, we write down the things that interact. Everything that is not in the system is necessarily outside the system. We often care about particular instance in the situation that we are analysing. So, we often care about where is the energy stored at time t-one. And we care about where the energy is stored at time t-two. Energy that is stored in the system remains inside the system and we show that with an arrow that remains inside the system. The arrow often represents a pathway from one storage mechanism to another storage mechanism. There could be work that is done on the system, and we call that work external. Energy that is flowing into the system comes in, energy obviously, that's flowing out of the system is an arrow that points out.

Work-energy bar charts are a qualitative representation of the relative amounts of energy at the different instance relating to our energy flow diagram. So we are interested in the question, how is energy stored at t-one? How is energy stored at t-two? And because of the construct of the work-energy bar charts, the sum of the energies on the left plus work external equals the sum of the energies on the right. So, we have two possible systems for this idea of dropping a ball. We could define the system as the ball only, which means the Earth is outside the system. Or we could define our system as the ball and the Earth. And then things like air would be outside the system. Things like the moon, would be outside the system. If those matter, we need to think about energy moving in and out of the system. In the ball only system, we need to think about energy moving in and out of the system. Now it's your turn. Pause the video. Complete the following two diagrams. And when you've had a chance to think about them, you can restart the video and take a look at the answers. (soft music)

So here's our basic setup. We have a ball. We have some gravitational energy. We have the option on some external work being done either by the system or on the system. And we have some motion at the end. So we have some energy being stored in the motion within the system. If our system is just the ball, Earth does work on the system, which we would show as a positive bar in the work column. And it gives the system kinetic energy. If our system is the ball and Earth, then the energy stored in the gravitational interaction is already inside the system. There is no external work. And we end up with energy stored in the motion after. So by defining our system as just the ball, we get a work-energy theorem analysis. If we define our system as the ball and the Earth, we get a conservation of energy analysis. Both of these will give the exact same answer. And this is why students struggle. Because without defining the system, it's not obvious to them, what's going on.

There is an algorithmic way to use work-energy bar charts. And it is a very useful way for the starting work with students. Certainly, in junior grades, this would be an excellent foundation. Where we list the more normal mechanisms or the, yes, the more normal storage mechanisms, like the energy stored in the gravitational field, the energy stored in motion, before and after. And then students are encouraged to make an X on the axis for any way of storing energy, energy storage mechanisms that they've considered and decided didn't play a role. There wasn't a change in that mechanism. And so this is what the falling ball example would look like if we use the more algorithmic approach, with work-energy bar charts. Again, a quick note of caution. Try not to leave your students in an algorithmic place for very long, because they will be not able to transfer to a more general application if it's always gravitational and kinetic energy.

One of the ideas that is interesting, is can we apply energy flow diagrams and work-energy bar charts to the photoelectric effect? As I was preparing this video, I said, okay, so I know what I'm going to do. I'm going to take the surface as my system. And then things are really straightforward. And I thought about it a little bit more and I realised, oh. But maybe I want the surface and the electrons in the surface to be my system. Okay, so there's two possible systems. I could take the incident photons and the surface and the electrons. Oh, I can take the incident photons and the surface and not the electron. Very quickly, I realised that there are at least four valid definitions of the system for the photoelectric effect. And we'll see how that affects the energy flow diagrams and the work-energy bar charts. And why it is, by not defining the system for our students, our students struggle with the photoelectric effect. So, let's go.

Energy flow diagrams, work-energy bar charts, we care about the instance where we have an incoming photon and T two, the electron has some speed, when it's emitted. And I'm intentionally choosing some speed and not some energy, just as a reminder that the energy is stored in the motion of the electron. Not, we have a type of energy called kinetic energy. So again, there are four possible systems. And here's my challenge to you. Here's your turn again. You've got a energy flow diagram and a work-energy bar chart. There are four possible systems. Take a moment. Pause the video. Sketch out how each of these becomes a valid analysis for the photoelectric effect. How each of them generates a different work-energy bar chart, so that the equations that follow for free, look different, but all of them are equally valid based on the definition of the system. (soft music)

Okay, welcome back. We have these four possibilities. Beginning in the upper left, where our system is the incident photon, surface on the emitted electron, all of the energy remains in the system. And here's a quick side note that you're going to want to think about with your students. Is that work external is different than the work function of the surface. So it's now, we're going to have students who run into a difficulty of work and work and work and work and which work do we mean. And all of it is just so much heavy travail that they will feel like they are working very, very hard. So, I've been very clear to label it as the energy that ends up being stored in the surface. If you want to get into the mechanism of that energy, you could probably even talk about it as its energy stored in the jiggle of the substance within the metal surface. Anyway, our photon energy is within the system. The electron motion is within the system. And the surface is within the system.

Going working our way across the diagram, our photon does work on the system. And that work ends up being stored in two different storage mechanisms within the system. It ends up being stored in the surface and in the motion of the electron. And you can see how the energy bar chart looks different. Or if I define my system to be the incident photon and the surface, then the electron is carrying its motion energy out of the system. And now we have a negative work being done because that energy is leaving the system and we would show that as a negative bar. The final one should be the surface only. And there the photon comes in, does work. Some of the energy remains stored in the surface and then some of the energy leaves as the electron. And here we end up with a positive work bar and a negative work external bar. Plus, the energy that is stored in the surface. So that's a quick look at how, the choice of the system completely changes what the students think is a valid analysis. And if we've not told the students what system we're dealing with, we know, we're happy, we're presenting a solution. They might make a valid assumption of a different system and then our process doesn't match theirs.

Remember this. They really want to understand. They really care. They're really trying. And they are just being hit by confusing information. Our job as teachers is to give them the clues to get through the mystery. A quick note on some of the pedagogy of teaching energy. Traditional treatments of energy, often create misconceptions for the students. And I started a little bit with this language at the beginning. We will often say things like ‘a ball has energy’. And that might be true if we're talking about it's mass-energy equivalence. But most often, we think of it as the ball that we're holding and getting ready to fall, having gravitational energy. Really, it's the system that we want to be thinking about. Something else that has been shown to really hamper students understanding, is the idea that energy comes in many forms. They often think of energy, the way we would think of fruit. Where you have apples and oranges and grapes. Where it's all fruit, but each is different. And yet we know by conservation of energy, that really all energy is just energy and it's the mechanism by which it is stored that is different. So, the energy resource that you can download from Perimeter, explores some of this language with you, so that you can help your students understand more clearly how energy can work.

Thank you very much for watching this video. There's some contact information here for you, for myself, and for Tonia, and for Sean. And we look forward to more interactions with you in the future. (soft music)

[Slide reads: Importance of Energy in the Stage 6 Physics course. Why invest in developing a deep understanding of energy?

* Energy provides a valuable tool for analysing physical phenomena and builds links between concepts.
* Students are required apply the law of conservation of energy to understand, account for and analyse a range of physical phenomena.
* Using precise language and representations of energy supports deep understanding and may avoid common student misconceptions.
* Guiding students in making choices when analysing the energy in a system prepares them for applying their understanding.]

Presenter: Why is energy important to the stage six physics course? Energy is a valuable tool for analysing physical phenomena and helps to build links between concepts. The course requires students to apply the law of conservation of energy to account for a range of physical phenomena. Our choice of language in the representations of energy that we use in our classrooms is critical. As it helps to support deep understanding, or alternatively may cause or reinforce student misconceptions. There is more than one way to look at a system. And it is important that our students recognise that all choices of system are equally valid. Demonstrating to students how their choice of what to include in the system impacts on their analysis will support deeper understanding of energy and prepare them to approach unfamiliar problems.

[Slide reads Syllabus links. Mechanics  
Students:

* investigate the relationship between the total energy and work done on an object executing uniform circular motion
* investigate the relationship of Kepler’s Laws of Planetary Motion to the forces acting on, and the total energy of, planets in circular and non-circular orbits
* derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to a variety of situations, including but not limited to the concept of escape velocity, energy of a planet or satellite in its orbit and the energy changes that occur when satellites move between orbits]

Mechanics is a familiar context for energy with energy interactions for objects in gravitational fields, being part of the dynamics module in Year 11. I've intentionally removed the list of equations describing the various energies when presenting these syllabus references. I did this because I wish to point out that building a conceptual and qualitative understanding before complicating the situation with a range of equations acts as a useful stepping stone to quantitative reasoning.

[Slide reads Syllabus links. Electromagnetism and modern physics

Students:

* analyse the interaction between charged particles and uniform electric fields including the work done on the charge
* evaluate qualitatively the limitations of the ideal transformer model and the strategies used to improve transformer efficiency
* account for the production of emission and absorption spectra
* model and explain the process of nuclear fission, including the concepts of controlled and uncontrolled chain reactions, and account for the release of energy in the process
* account for the release of energy in the process of nuclear fusion.]

Beyond the more familiar context of mechanics, students must also apply their understanding of energy to investigate a range of electromagnetism and modern physics processes.

[Slide reads Syllabus links. Applying conservation of energy or conservation of mass-energy to:

* analyse the photoelectric effect
* account for the line emission spectrum of hydrogen
* analyse artificial nuclear transmutations, including alpha decay, beta decay, nuclear fission and nuclear fusion
* predict quantitatively the energy released in nuclear decays or transmutations, including nuclear fission and nuclear fusion.]

Students must also directly apply conservation of energy or mass-energy to account for and analyse the photoelectric effect, emission spectra and nuclear transmutations.

Thank you again, Laura. And the outreach team there at the Perimeter Institute. To download the resources referenced in this video, please follow the link to the Perimeter Institute Resource Center. All of their resources are free, modifiable and available as either PDF or Word. In English, in French. Portuguese and hopefully soon Spanish. Would you like to stay updated on future resource releases, training and other news from the Perimeter Institute? Please complete the attached form to register for their outreach updates and newsletter. (soft music)

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