Science-Physics-Perimeter- Nuclear Transmutation Fusion transcript  
   
(Duration 20 minutes 39 seconds)

(upbeat 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 are 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.

[Slide reads: Perimeter Institute resources  
Activity 1: The conservation and transformation of energy  
Activity 2: Innovative technologies  
Activity 3: Nuclear transformations  
Activity 4: Ionizing radiation  
Activity 5: Mass-energy equivalence  
Activity 6: Where do the elements come from?  
Activity 7: Conservation laws and dark energy

<https://resources.perimeterinstitute.ca/> ]

Welcome to our Perimeter Institute video workshop, Nuclear Transmutation: Fusion. This workshop is being developed to support teachers in New South Wales, implementing a curriculum for energy and nuclear transmutations. It will focus and relate to several activities from one of the Perimeter Institute resources called, ‘A Deeper Understanding of Energy’. All of our resources are available for free to teachers around the world at the web address given on this slide. You will receive a download of a PDF of the teacher resources including teaching tips, teaching strategies, what you need, areas of potential misunderstandings that your students might have, and you will get word editable student activities that you can suddenly tweak to align exactly for your students and exactly for what you need them to do. We are going to talk briefly in this video, about activity one and ideas of conservation and transformation of energy. A little bit about activity three, nuclear transformations, the key idea in activity three is that radioactive decay should be talked about as a nuclear transformation rather than a decay because the nucleus doesn't disappear. It's one of those subtle wording changes we can make that really help our students to understand the physics more deeply. Ionizing radiation here, deals mostly with medical applications of ionizing radiation. But it relates clearly to things like ionizing radiation happening in space as electromagnetic radiation passes by clouds, or when we look at the different colours of flames in a flame test in a chemistry lab. There is a very high level nod towards mass-energy equivalence and how we can help students understand that, but really we want to focus on activity six, and where do elements come from.

[Slide reads: What is ‘energy’?

“In speaking of the Energy of the field, however, I wish to be understood literally. All energy is the same as mechanical energy, whether it exists in the form of motion or in that of elasticity, or in any other form. The energy is electromagnetic phenomena is mechanical energy. The only question is, ‘Where does it reside?’”  
James C. Maxwell]

One of the key ideas coming out of "what is energy", is that energy is an observed change. The concept of energy is something that as physicists or as scientists, we can use to analyse a system. And so to make an energy analysis work, we need to understand ourselves and identify clearly the system. We don't have different forms of energy, we have energy stored in different mechanisms, in different storage areas. We recognise that this idea of, where is the energy stored, where does it reside, if we use the language of James C. Maxwell, we get an idea perhaps that energy is a physical thing. It is a fluid perhaps, that lives in things. This is a misconception that we need to be mindful of, that our students might be picking up as we do this work.

A quick review of multiple representations for energy. Again, multiple representations are an excellent pedagogical device because it helps students understand and translate from one form to another. When there's a disagreement between the representations, this can identify where they have a weakness and understanding. An energy flow diagram starts with the definition of a system. And in the system, you write down the things that interact, you identify the instants that you care about, perhaps the initial instant which would be t-zero, at some later time t-one, at some later time t-two, et cetera. We would be using the subscripts, E-zero, E-one, E-two, for the different instants for how the energy is being stored at those different systems. Energy that is stored in the system remains in the system and we would show this with an arrow between one kind of energy to another mechanism. Work is energy that is either flowing into or flowing out of the system. We know that there will be work when the total energy within the system is changing. To complete a work-energy bar chart, on the left of the grey column, we look at how the energy is stored before, and on the right hand side, we look at where the energy is stored after, and the grey bar lets us deal with work done on the system. So the grey bar is neither the before or the after, but it is something which is being done to, or by the system. If it's work being done on the system, we would put a positive bar in and if it's work being done by the system, then we would put a negative bar in.

So let's look at this hands-on model. We're going to observe it in action, and then we're going to build an energy flow diagram and a work-energy bar chart, for what's happening here. I want to change to a different camera view so that you can see it actually happening. [Video plays of the experiment] (track moving) As described, we have a metal ball, we have a folded card, we have a stopper. (ball rolling) If I give the ball a small tap it rolls towards the card. The card bends. (ball rolling) And the ball comes back. (ball clicking)

Here is your opportunity. I invite you to pause the video, build an energy flow diagram and a work-energy bar chart for the system of the ball and the card. T-one has the ball rolling along the track toward the card, t-two is the instant where the ball is temporarily stationary and the card has its maximum compression, t-three is the ball rolling back along the track. Now, there's a little note on the bottom of this slide that says, "Assume that there is no magnetic interaction." The stopper in my apparatus is a magnet and we need that for the next part of this activity. So, your turn, build an energy flow diagram, a work-energy bar chart, and then restart the video. (upbeat music)

Welcome back. Here is one possible representation for an energy flow diagram and the work-energy bar charts, for the steel ball rolling on the track. I do work on the system, when I flick the ball to start it rolling. That's represented by an arrow coming in, it's represented by a positive orange bar in the first work-energy bar chart. That energy is stored in the motion of the ball. Well, the ball is moving so, t-one while the ball is moving, I have energy stored in the motion. At t-two where the card is compressed and the ball is stationary, I have no motion, so I have no energy starting kinetic energy, all of my energy has been stored in the change of shape, the deformation of the card. And then when the card returns to its original shape, the ball comes back with its same kinetic energy. This is where we fall into that subtle problem with the language. The ball doesn't have kinetic energy, the system has kinetic energy, the ball has motion. This is an example of how difficult it is to get past some of these misconceptions that we carry from our years of teaching energy subtly differently.

[Slide reads: Predict, explain, observe, explain

What needs to happen so that the system at t-three has all its energy stored in something other than motion? Why?

Let’s try: What did you observe?

What is the interaction? What symbol could we use?]

If we were doing this workshop with you in person, I would do a predict, explain, observe, explain activity. I've left the slide in knowing that it's a video, knowing that I'm not doing this with you in person, because I wanted to talk just briefly about this excellent teaching tool. The "predict", "explain", asks students to come up with a prediction for what's going to happen and to be sure they know why they want that to be their prediction. This "explain" is a necessary step for them to then be able to challenge their understanding. If they don't explain and you jump immediately to the "observe" and "explain", they can get away with just adding your explanation to their memorized approach to things without understanding that they might need to adjust their thinking.

So here's the idea. What needs to happen to this system of the ball and the card and the stopper, so that all of the energy that is initially stored in the motion, gets stored in some other mechanism? Why? Okay, we're going to do it. In order to overcome the shape of the card, I need to give the ball (ball clicking) more kinetic energy. Whoa, whoa. (ball rolling) Or maybe I need to give it too much kinetic energy. (ball clicking as it attaches to magnet) My system is still the ball and the card. Where did the energy go? I’m now observing no change, it went somewhere, where did it go? It's stored in the magnetic interaction now between the magnet and the steel ball, and in the compression of the card. For more information about how fields store energy, I invite you to look at our fields resource. Again you can download it for free and it explores all kinds of neat ideas about how fields store and transfer energy.

Now, let's think a little bit more about this fun hands-on activity where students can roll a steel ball and have it (claps) connect to a magnet, and we're going to apply that to something that we cannot do in the classroom, which is the fusion of hydrogen-2and hydrogen-3 to temporarily produce a helium-5 nucleus, which has more energy than it knows what to do with, emits in neutron, emits a helium nucleus, and we get some electromagnetic energy being emitted as light. We can in fact, map that track apparatus exactly to this nuclear fusion model. So, I would invite you to pause the video, complete this chart, comparing the features of the apparatus to nuclear fusion, and when you come back, we're going to talk about, we’ll both complete the chart and then we'll talk about whether this is a strong model or a weak model. And again, some of the ideas behind using models to help our students. So, pause the video, complete the chart. (upbeat music)

And welcome back. Hopefully you got a chart that's something like this. The hydrogen-2 could be represented by the steel ball, the track is the path of the incident proton, the incident hydrogen-2, the magnet then becomes the hydrogen-3, and that connection happens because those two end up sticking together. The magnetic force that holds the ball to the magnet is analogous to the strong nuclear force. The folded card becomes analogous to the coulomb barrier. And again, the activity that we've done where the ball is rolling and bounces back, is an example of a failed fusion reaction where the hydrogen-2 and hydrogen-2, don't have enough kinetic energy to overcome the coulomb barrier. One of the things that when you do this with your students, you will hear a click as the ball slams into the magnet. And that becomes very analogous to the photon of electromagnetic energy that is emitted. So we have a model and this model is generally pretty solid. One of the things that you could do when you use this model with your students too, is talk about what do you need to do now, if you wanted to create fusion, if you wanted to pull something out of this helium-4 nucleus that you've created. The resource, ‘A Deeper Understanding of Energy’, has some notation. And I just want to include this now because I want to use... We're going to talk about a bunch of the like, the mass energy equivalence, that mass is energy, that light is energy, and that the energy stored in motion is kinetic energy. So that we have this idea of some of the notation that we're going to use, because we want to build an energy flow diagram and a work-energy bar chart for a system of all the nuclei. That's not the only system we could define. If you want more ideas about how to define systems, you could look at the other video Visualising energy that has been developed to help the New South Wales teachers.

The instants that we care about, t-one has the hydrogen-2 and the hydrogen-3 nuclei moving toward each other. T-two is the stationary helium-5. And we have no difficulty defining our system to be the stationary helium-5 because we just define our frame of reference around that point in our analysis. And then t-three is the helium-4, the neutron and the photon. When you're done, start the video up again, and we'll look a one possible answer. (upbeat music)

Welcome back. Here is one possible answer for the work-energy bar chart and the energy flow diagram, for nuclear fusion. When we start, our hydrogen-2 and our hydrogen-3 are both moving, so we have kinetic energy, energy stored in the motion of these nuclei before any interaction occurs. We also have their mass-energy. So we have energy stored in motion at time one, and we have energy stored in mass at time one. At time two, all of that energy is stored in the mass-energy, in the mass of the helium-5. At instant three, we have some energy stored in the mass of the helium-4 and in the motion of the helium-4, and we have a bunch of energy leaving the system as the mass energy of the neutron, the motion of the neutron, and the photon energy. At the bottom of the screen, there is a collection of questions. These are the questions that I love to ask students. “What I've given you is one possible answer. Does it agree with yours?” And I'm always ecstatic when my solution and the students' solution don't agree. Because it means that the students and I have made slightly different starting assumptions, we've made slightly different initial conditions, and that allows me to have a deep conversation with the students about what they're doing. It often points out, nuances that I have not been thinking about in developing my solution.

I've included the question is one wrong, intentionally to get people's backs up. I really hate the idea of students making mistakes as they're learning. The learning process is a messy process. And we talk about that in all our resource tools for teaching science, which will be available in September, 2020. And students aren't making mistakes as they're learning. Students are struggling with their prior understanding and this new information that we are giving them, and they're trying to figure out how to get those ideas to work together. They're modifying their understanding and they're making attempts, and we need to be celebrating with them as they make attempts.

Again, all of our resources are available to you for free at the https://resources.perimeterinstitute.ca. You will get a PDF version of the teacher resource including teaching tips, lesson plans, possible misconceptions your students might be carrying, ideas on how to do hands-on activities with students to get a very abstract ideas, and modifiable word documents. Thank you very much for spending some time with us today. Here is some contact information if you want to reach out to us for more help. (upbeat music)

Announcer: 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 Centre. All of their resources are free, modifiable and available as either a 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. (upbeat music)

End of transcript