NEWSLETTER

ONTARIO ASSOCIATION OF PHYSICS TEACHERS (An Affiliate of the A.A.P.T., and a charitable organization) April, 2010

Modern Physics

Quantum Tic-Tac-Toe

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Quantum physics is weird but it does have rules – they are just different from those of classical physics. These rules involve the three key concepts of **superposition, entanglement** and **measurement-disturbance**. One great way to get a feel for these rules is Quantum Tic Toe. It is similar to classical TicTac Toe – but with quantum-like rules. When you make a move, you select two boxes where you might be – not one box where you definitely are. This is like an electron in a double-slit experiment – it could have gone through either one slit or the other. Your move, like the electron, is in a superposition of states. One possible first move is shown in Figure 1. Next, your partner makes a similar, indeterminate move as in Figure 2. You can then respond as in Figure 3.

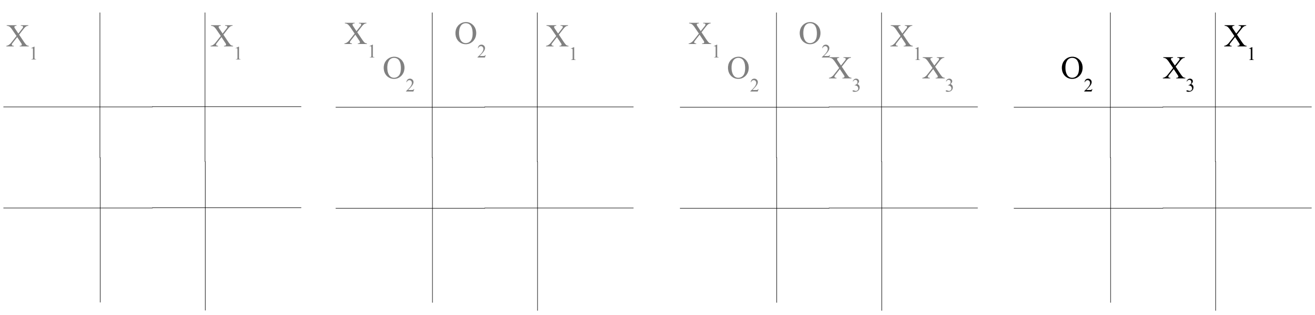


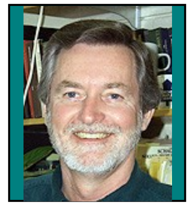
Fig. 1 Fig. 2 Fig. 3 Fig. 4

But wait! Now there are three boxes and three letters. There is no further room in these boxes and the moves are entangled. Entanglement is probably the weirdest feature of quantum physics. Measuring the state of one entangled particle instantly determines the states of the others. In classical physics, properties or states exist objectively. In quantum physics they often don't exist until we measure them and our measurements change the outcome. That's why if you measure which slit an electron goes through – you lose the interference pattern.

Consider the middle box. There is a 50:50 chance that it will contain an X. Let's flip a coin. Suppose it is an X. That means that the right corner must contain the first X and so the O must be in the left box. The game now looks like Figure 4. If the middle box had contained an O, then the game would show X, O, X across the top. Before the measurements there were two possible games being plated - now there is just one. This models how quantum computers can be so powerful. They do many calculations at once, just as we can play many games at once. You will find more information about this game at http://www.paradigmpuzzles.com/QT3Play.htm. If you play it on line, it will keep track of the superpositions and entanglements and show you all the classical games that you are playing at once.

The Demonstration Corner

Can You See Sound ?



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This demonstration is a nice way to show that sound is vibration of molecules. Figure 1 shows the equipment required for this demonstration. The setup consists of an amplifier attached to an input device (laptop, iPod, mp3 player, etc) and a set of small speakers (described below) as well as a bar clamp and red and green laser pointers.

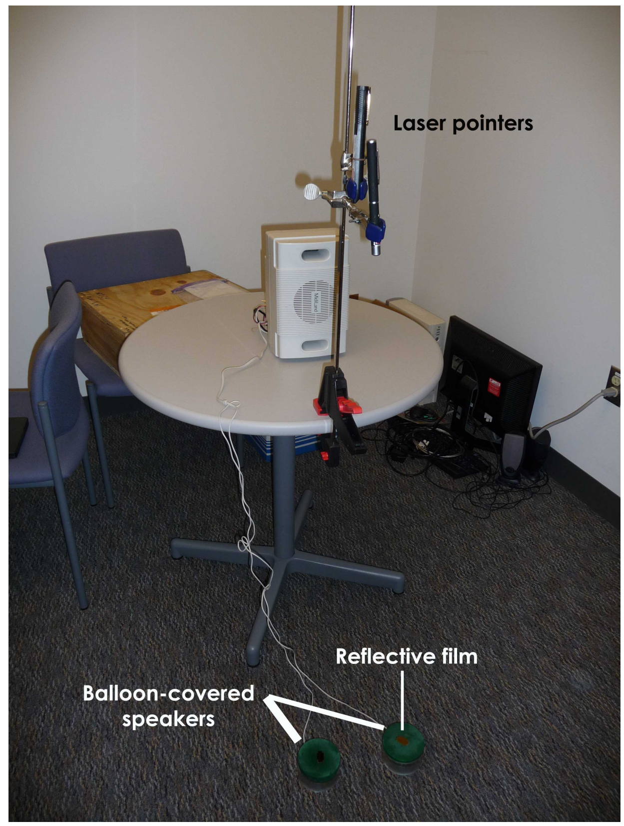

Figure 1 Equipment setup for demonstration.

Two small speakers are mounted inside plexiglass tubes so that there is space above and below the speaker. A groove is etched around the outside of the tube about 1 cm from the top of the tube. Latex balloons with the ends cut off are stretched across the top of the plexiglass tube. The balloons can be held in place by stretching the balloon past the groove and then wrapping elastic bands around the tube in the groove. A reflective film is attached to the balloon in the center of the speaker. I use gold-coated mylar film as tin-foil diffuses the light too much. You can try using a small piece of a CD or mirror. The speakers are set on the floor and plugged into an amplifier that has some input device attached. I use an iPod but you can also ask students to use their own input device with their favourite music. A bar clamp is attached to the table or bench with the amplifier. Laser pointers are attached to the bar clamp so that the green laser shines on the reflective film on one speaker while the red laser shines on the reflective film on the other speaker.

I ask students what sound is and initiate a discussion about sound, as well as how and where sound waves travel. I have them put their ear against a desk and knock lightly on the desk so that they realize that they can feel as well as hear sound. I then ask them if they can see sound and if they want me to demonstrate the ability to see sound. I dim the room lights and then turn on the iPod and amplifier. As the speaker emits the sound waves, the vibrating air molecules cause the balloon to vibrate which in turn moves the reflective film. The laser beam, which is reflected from the film onto the ceiling, moves with the music. To reinforce that the movement of the laser beam is due to the sound waves, I change the volume. As the volume increases, so does the movement of the laser beam.

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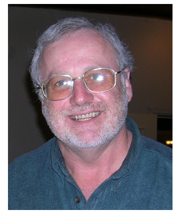
Submissions describing demonstrations will be gladly received by the column editor.

High School Physics

Faster than Gravity: The Curious Case of the Bungee Jumper



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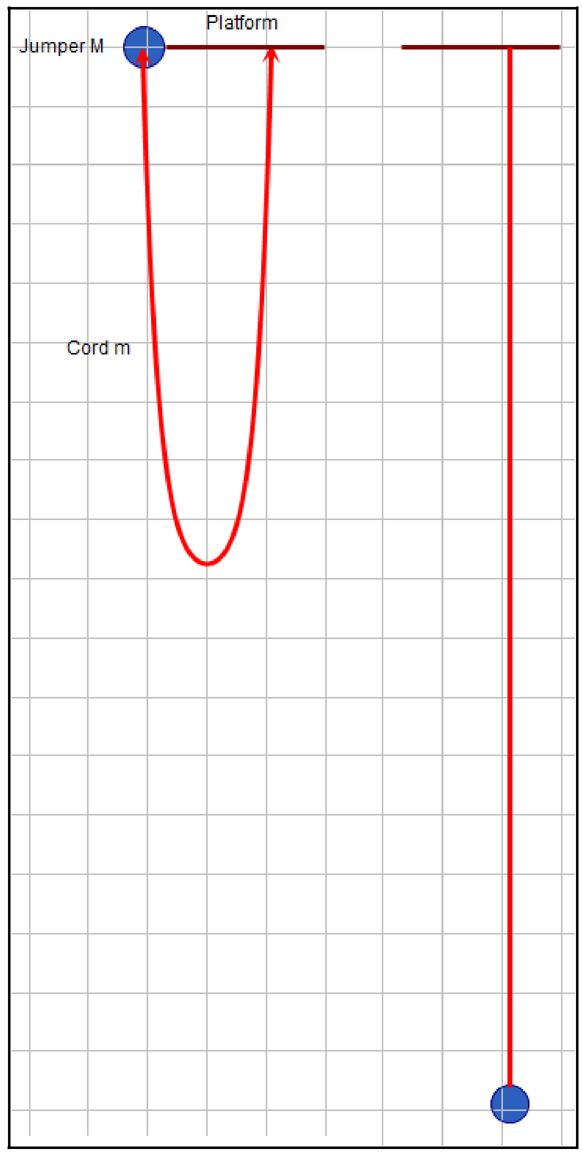
On a recent trip to New Zealand, I stopped in at the A. J. Hackett bungee jumping centre near Queenstown, the world's first commercial bungee jump. The chance to experience Hooke's Law from the point of view of the hanging mass was too good to miss, so I plunked down my credit card for an exciting jump off the historic Kawarau River bridge (see the action picture), a drop of 43 m (or 15 storeys, if that is easier to imagine). On my return home, I did some research on bungee jumping, and came across a curious anomaly.

Consider a bungee jumper of mass M, tied to a bungee cord with mass m, jumping from a platform, and falling until the bungee cord reaches its rest length. During this part of the jump, how can you describe the acceleration of the jumper?
As usual, ignore air resistance.

a) constant acceleration g
b) zero increasing to g
c) zero
d) g increasing to kg, $k > 1$
e) g decreasing to kg, $k < 1$, $k \geq 0$



The most attractive answer is usually a), since the jumper appears to be in free fall during this part of the jump, and we are ignoring air resistance. However, the correct answer is d). The acceleration of the jumper begins at g, but then increases to a value greater than g.

The theoretical equation that governs the value of k is[1]:

$$a = \left[1 + \frac{m(4M + m)}{8M^2}\right] g$$

For example, a jumper with a mass of 100 kg using a cord of mass 25 kg will have an instantaneous acceleration of 1.13g at the time the cord reaches its rest length.

Why does this happen?

Consider the jumper just as he steps off the platform. The bungee cord hangs more or less as a catenary. The gravitational potential energy of the cord in this position is higher than the gravitational potential energy when it is hanging at its rest length.

As the jumper falls, part of the cord is falling, and part is not. The former decreases to 0 as the rest length of the cord is reached. The extra potential energy that the cord possessed initially has been transferred to the jumper through internal elastic forces within the cord. Just how this takes place is not trivial. Refer to the article below for more detail.

As a result, the speed reached by the jumper at the instant the cord reaches its rest length is higher than it would be for a freely-falling jumper. The average acceleration during this part of the jump must be greater than g.

This effect can be demonstrated in the classroom, or assigned as a student project. Set up a falling "jumper", perhaps a 1 kg mass, and use a heavy chain as the bungee cord. Measure the position and time for the jumper using a sonic sensor or a video camera. Use the position-time data to determine the instantaneous acceleration at convenient points during the jump, and graph the results.

The greater the ratio between the mass of the chain m and the mass of the jumper M, the greater the deviation from free-fall acceleration g. If the mass of the chain exceeds M, the change in acceleration is dramatic. If, for example, if $m = 2M$, $a = 2.5g$. This is visible to the human eye. You can demonstrate the effect by dropping another mass without a chain in parallel with the mass attached to a chain.

The oldest person to perform the Kawarau jump was 94, and the youngest was 10. The heaviest had a mass of 235 kg. The tallest of the jumps available in Queenstown drops 234 m. You can visit A. J. Hackett at http://www.ajhackett.com/.

For more detail and a rigorous mathematical derivation, see the reference below. For video action visit www.youtube.com, and search using the keywords bungee kawarau.

[1] *The Physics Teacher* Volume 34 September 1996