Energy of a Roller Coaster

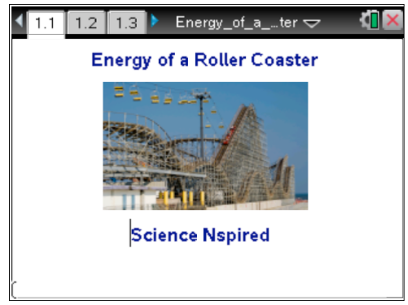
Student Activity

Name ________________

Class ________________

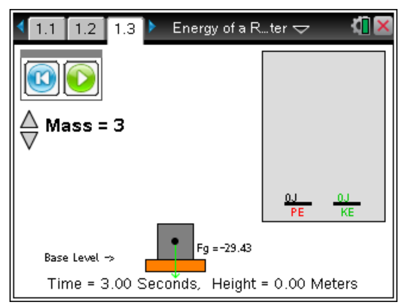
Open the TI-Nspire document *Energy_of_a_Roller_Coaster.tns.*

What gives a roller coaster its high speed? How does it complete the track without an engine? A roller coaster is a great example of energy transformation. Roller coaster designers must keep energy considerations at the forefront of their designs in order to create exciting, workable rides. In this activity you will explore some of the basic energy ideas behind roller coasters.



When a force is applied to an object and the object moves in the direction of the force, the force does work on the object. Work is defined as the product of the displacement of the object, Δx, and the component of the force in the direction of the displacement, F_x. Gravitational potential energy (PE) can be described as stored energy an object possesses due to its height above a reference point. It is calculated by multiplying the weight of the object, mg, by its height above the reference, *h*. Kinetic energy (KE) is the energy an object possesses due to its motion. This is calculated by the formula $KE = \frac{1}{2}mv^2$. Work, potential energy, and kinetic energy are all measured in Joules (J).

Move to pages 1.2 and 1.3.



1. Read the information on page 1.2. After reading the directions on page 1.3, select ☒ to close the pop-up box.
2. On this page you will find a block on a surface. You may grab the block by the point in the middle and lift it above the surface. The force required to lift the block and the height of the block above the surface is displayed on the screen. The product of these numbers is the work done on the block. As the block is lifted, a bar graph measures its gravitational potential energy. Another bar graph measures the kinetic energy of the block.

Answer questions 1–3 here as you work through the simulation before moving to page 2.1.

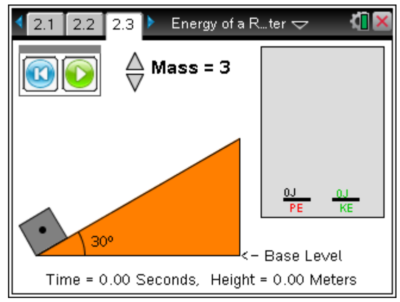
Q1. Grab the block and lift it above the surface. Then use the spaces below to record the lifting force and the height to which you lift the block. Use these numbers to calculate the work you do on the block. Observe what happens to the gravitational potential energy as you lift the block. Select the play button ▶, and observe the gravitational potential and kinetic energies of the block as it falls.

A. F = ______N   B. h = ______m   C. $W = F \cdot h$ =______J

Q2. Describe what happens to the gravitational potential energy of the block as you lift it. Compare the potential energy at the highest point to the work done in lifting the block.

Q3. Describe what happens with the gravitational potential and kinetic energies as the block falls. What do you observe about the sum of the two energies as the block falls? Compare the kinetic energy of the block when it reaches the surface to the gravitational potential energy when you released it.

Move to pages 2.1–2.2.



3. Read the information on pages 2.1 and 2.2. After reading the directions on page 2.3, select to close the pop-up box.

   Roller coasters are not lifted straight up, and they do not fall freely. Instead, they move up and down hills. In this activity, you will see a block with a mass of 3 kg at the bottom of an incline. First you will note of the **force** required to pull the block and the **distance** it is pulled. The product of **force** and **distance** is equal to the work done on the block. You will then observe the **potential energy** of the block at the top of the incline. Finally, you will see the **potential** and **kinetic** energies of the block as it slides down the incline.

Move to page 2.3.

4. On this page, a 3-kg block starts at the bottom of a frictionless hill. Grab the point in the middle of the block near the corner of the incline and move it up to pull the block up the incline. The force required to pull the block and the distance pulled are displayed on the screen. As the block is pulled up the hill, a bar graph measures its potential energy. As the block slides down the hill, another bar graph measures its kinetic energy.

Answer questions 4–6 here before moving to page 2.4.

Q4. Drag the block to the top of the incline, and record the distance and the force required to pull the block to this location. The work done on the block is the product of these two numbers. Observe the potential energy as the block is pulled up the hill. Select the play button, and observe the potential and kinetic energies of the block as it slides down the incline.

A. F = ______N B. d = ______m C. $W = F \cdot d$ = ______J

Q5. The block has a mass of 3 kg, and the hill is a 30° incline. Demonstrate how the height of the block at the top of the hill can be calculated. Use this height to calculate the gravitational potential energy at the top of the hill. Compare your calculation of gravitational potential energy to the work calculated in the previous question.

Q6. Describe what happens with the gravitational potential and kinetic energies as the block slides down the hill. What do you observe about the sum of the two energies as the block slides? Compare the kinetic energy of the block when it reaches the surface to the gravitational potential energy when you released it.

Move to pages 2.4–2.6. Answer questions 7–9 here and/or in the .tns file.

Q7. The potential energy of an ideal roller coaster at its highest point is equal to the work required to get it to the top of the hill.

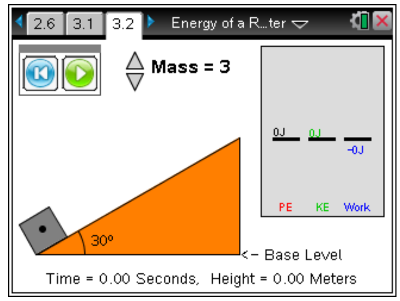
A. True B. False

Q8. Choose the correct statement(s) about kinetic energy, KE, and potential energy, PE, based on your observations of the block on the frictionless incline. (There is more than one correct statement.)

A. The KE and PE of the block are always equal.
B. As the block slides down the hill, its KE increases at the same rate as its PE decreases.
C. As the block slides, the sum of its KE and PE remains constant.
D. The total energy of the block (KE + PE) increases as the block slides down the incline and gets faster.
E. The greater the height of the block when it is released, the more KE it will have when it reaches the bottom.

Q9. On an actual roller coaster, how does it gain its initial gravitational potential energy?

Move to pages 3.1 and 3.2.



5. Read the information on page 3.1. After reading the directions on page 3.2, select ☒ to close the pop-up box.

6. Grab the block and lift it up the ramp. Then, select the play button, and observe the work and energy bar graphs as the block slides. The work shown is the work done by friction on the block.

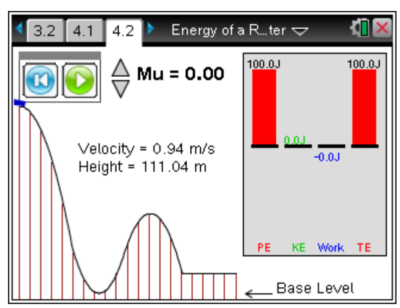
   A more realistic picture of the block on a hill includes friction resisting the motion of the block. On an actual roller coaster, friction and air resistance oppose the motion. Forces that oppose motion do negative work on the object. This **work** is **negative** because the direction of the friction force is opposite to the direction of motion. This simulation includes a friction force acting on a 3-kg block as the block slides down a 30° incline.

Answer questions 10 and 11 here before moving to page 4.1.

Q10. Note the gravitational potential energy of the block at the top of the hill. Select the play button, and observe the work and energy bar graphs as the block slides. Describe the changes you observe in the gravitational potential energy and the kinetic energy of the block as it slides. Compare the kinetic energy at the bottom of the hill to the gravitational potential energy at the top.

Q11. How much work was done by the friction force? What effect did this appear to have on the energy of the block?

Move to pages 4.1 and 4.2.



Page 4.2 simulates a roller coaster car moving along a track. The height and velocity of the car are displayed. On the right side of the screen are bar graphs for potential energy, kinetic energy, total mechanical energy, and work done by friction. The total mechanical energy is the sum of the potential and kinetic energies.

7. After reading the directions select ☒ to close the pop-up box. The roller coaster car is already at the top of the track. Select the play button will release the car. Selecting the reset button will place the car back at the top of the roller coaster. You may change the friction, μ, by selecting the up and

down arrows (▲ or ▼) for Mu.

Answer questions 12–21 here before moving to page 4.3.

Q12. Set the value of Mu to zero. Select the down arrow ▼ a couple times until it shows Mu = 0.00. Start the car and allow it to move through the track. Observe the bar graphs as the car moves along the track. Describe the changes you observe in the potential energy, kinetic energy, and total energy. Comment on how the three energy measurements appear to relate to each other.

Q13. Reset the car and set the value of Mu to zero. Stop the car at the bottom of the first hill. Record the values of the PE, KE, TE, height (*h*), and velocity (*v*). Repeat these steps, this time stopping at the top of the second hill. Repeat the steps again, this time stopping at the bottom of the second hill.

top of the 1st hill	PE = ______J	KE = ______J	TE ______J	*h* = ______m	*v* = ______m/s
bottom of 1st hill	PE = ______J	KE = ______J	TE ______J	*h* = ______m	*v* = ______m/s
top of the 2nd hill	PE = ______J	KE = ______J	TE ______J	*h* = ______m	*v* = ______m/s
bottom of 2nd hill	PE = ______J	KE = ______J	TE ______J	*h* = ______m	*v* = ______m/s

Q14. Calculate the ratio of the potential energy at the top of the first hill to the gravitational potential energy at the top of the second hill. Now calculate the ratio of the height of the first hill to the height of the second hill. What do you observe about the two ratios? What does this tell you about the relationship between gravitational potential energy and height?

Q15. Calculate the ratio of the kinetic energy at the bottom of the first hill to the kinetic energy at the top of the second hill. Now calculate the ratio of the speed at the bottom of the first hill to the speed at the top of the second hill. What do you observe when you compare these two ratios? What can you infer about the relationship between the kinetic energy of the roller coaster and its speed?

Q16. At the bottom of the second hill, what percentage of the roller coaster's total energy is in the form of potential energy? What percentage is in the form of kinetic energy? What percentage of the maximum speed of the roller coaster is its speed at the bottom of the second hill?

Q17. Move the roller coaster back to the beginning of the track. Change the coefficient of friction to $\mu = 0.1$ so that friction will act on the roller coaster and do negative work as it moves along the track. Select the play button and observe the bar graphs as the car moves along the track. A new bar graph measures the work done by the friction force. What happens to the total mechanical energy of the car as it moves along the track?

Q18. You have probably heard a statement similar to "Energy is neither created nor destroyed, but it may change forms." With this in mind, how can you explain what is happening to the total mechanical energy of the car? What effect is friction having on the car? (Hint: Think about what happens when you rub your hands together rapidly.)

Q19. Friction and air resistance are classified as non-conservative forces. In contrast, the force of gravity is classified as a conservative force. Explain what this means in the context of this simulation and your observations above. (Hint: In physics, a quantity is conserved if it remains constant as other quantities change.)

Q20. Compare the speed of the car at the bottom of the first hill in this simulation to the speed of the car at the bottom of the first hill when there was no friction. What difference do you observe? Is this consistent with your observations above?

Q21. With friction opposing the motion, could a roller coaster make it to the top of a hill, which has the same height as the starting hill? Explain your answer.

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Move to pages 4.3–4.6. Answer questions 22–25 here and/or in the .tns file.

Q22. A roller coaster achieves maximum speed (ignore friction) __________.

A. at the bottom of any hill

B. at the lowest position of the track

C. anywhere on the track which is not at the top of a hill

D. part way down the first hill

Q23. To increase the maximum speed of a roller coaster, a designer should __________.

A. make the track shorter

B. make the track longer

C. have fewer hills

D. make the first hill taller

Q24. In the absence of friction, the greatest height a roller coaster can achieve __________.

A. is higher than the first hill

B. is much lower than the first hill

C. is equal to the height of the first hill

D. is determined by the most recent hill it has passed over

Q25. A roller coaster will stop _________.

A. when its potential energy is equal to its total energy

B. only if it crashes into something

C. at the top of any hill regardless of its height

D. when it runs out of gas

