Instructors Guide to:

Current due to Electro-Motive Force defines limiting speed of motion of a car down an incline.

The EMF produced by changing flux of magnetic field is always appears in polarity that would create the current in the closed loop, reducing change of magnetic flux that produces EMF. This can happen if there is a coil, made of wire, in which this EMF creates the current. The smaller is the resistance of this loop the higher is the current and hence the larger is the torque in the direction opposite to the direction of rotation. Connecting a resistor to the contacts of the DC generator closes the loop and the current in this resistor and the coil is proportional to the EMF and inversely proportional to the resistance of the resistor and the coil connected in series. For example, for the car moving on incline with open contacts of DC generator (no current) the acceleration is defined by the component of the force of gravity along the incline and by a frictional torque in the wheels. The net force is constant, as well as the acceleration, so the speed is changing with time. The example of such a motion is shown in the first movie. However, in case the resistor (or a bulb, or a LED) is connected between the contacts of the DC generator, the motion is quite different. The torque due to the current in the coil is proportional to the speed of rotation, and its direction is opposite to the direction of rotation. As a result, the car reaches such a speed that the acceleration becomes zero, so the speed is constant, as it can be seen in the second movie. An increase of the angle of the incline results in the motion with a higher limiting speed but still without an acceleration on the most of the way, as the third movie demonstrates (note the light from LED’s becomes brighter due to increased current). The effect demonstrated is similar to a free fall in case when the air resistance can not be neglected.
In the Classroom:
Grade Level: 9-12
Building Skills: any skills
Programming Skills: Investigator

Time: 1-2 hrs.

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Challenge
Building a model of a car with one LEGO motor which will be used not as a motor but as a generator. The rotor of the generator will be rotating by the wheels of the car when the car is moving down the incline. The current through the coil of the generator is produced by the Electro-Motive Force (EMF) and controlled by the resistance of the load connected to the generator. In case the load is not a resistor but the LED (Light Emitting Diode which conducts current only in one polarity but not in the opposite one) then the polarity of LED defines if the current due to EMF will or will not go through the LED. As a result the torque opposite to the direction of the rotation depends on the polarity of the LED.

Materials
List the materials needed
RCX, parts for a 1-motor car (or an already made car).

Skills Learned
Design, Building, Programming.

Procedure
1. Build a LEGO car according to the instructions that can be found below.
2. Connect LED to the 2×2 wire plate which should be connected to the generator and, for measuring the voltage on the LED, to one of the input ports (1-3).
3. To set up an incline plane take any 2-3 ft. long board and install it at 10-30 degrees angle.
4. Before you start the experiment on the incline, determine at direction of the motion of the car the LED will emit light (due to current that goes through it).
5. Put the car on the incline on such a position that LED will emit light when the car goes down the incline. You will notice that the car is moving with constant speed and that can be checked by reading the voltage on the LED during the motion (it will be constant, on the most of the part except the very beginning when the car accelerates to reach the constant limiting speed).

6. Try to increase the angle of the incline and repeat the experiment. You will notice that the car will again move with a higher but still a constant limiting speed.

7. Test what happens if the car is placed on the incline in the opposite direction so LED will not emit light during the motion. You will clearly see that unlike the previous experiment the car will move with an acceleration (faster and faster).

8. The effect of reaching limiting speeds at different angles of incline illustrates that torque due to the EMF is opposite to the direction of the rotation of wheels and increases with the speed of motion until the speed is not changing anymore.

**Lego Tips**

To build LEGO car refer to the instructions for building a one motor car given on the website:

http://www.ceeo.tufts.edu/robolabatceeo/References/constructopedia/constructopedia.pdf

**Extensions**

In addition to the generator install the LEGO rotation sensor attached to the wheels of the car and connect the sensor to another RCX input to read the rotational velocity.
Sample Program – Inventor 4

Program for this experiment is very simple and includes only reading of the data on voltage on the LED and, as an extension, on the LEGO rotational sensor.

Sample Project