

The Domino Effect

Use dominoes to model a nerve cell's transmission of a signal

Your nervous system does its job by transmitting information through the long bodies of individual nerve cells as electrical impulses. Falling dominoes can simulate how a nerve cell is triggered and how it sends its impulse from one end of the cell to the other.

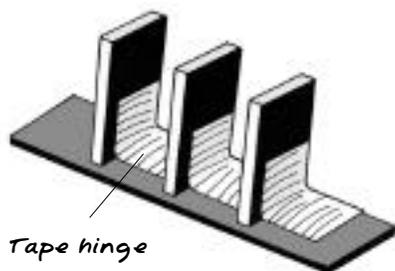
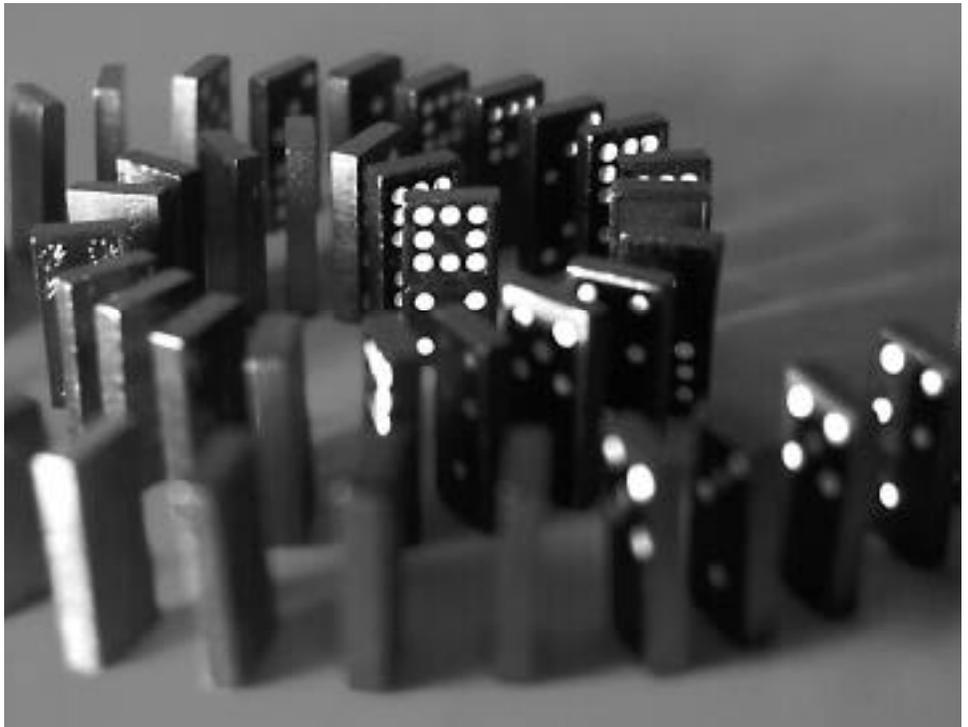


Figure 1A: Setup of dominoes with tape hinges

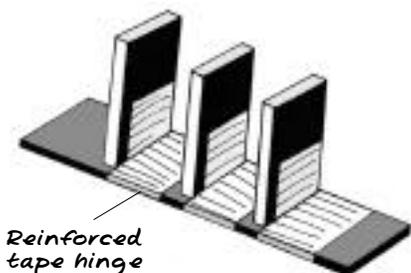


Figure 1B: Final setup of dominoes

Things You Will Need

- ▲ ruler, 30 cm or longer
- ▲ 8 standard dominoes
- ▲ masking tape
- ▲ scissors
- ▲ paper for recording observations

To Do and Notice

Constructing the Model

- ❶ Measure the length of one of your dominoes. Record the length.
- ❷ Cut 8 pieces of masking tape, each about the same length as a domino. (They don't need to be exact.)
- ❸ Place the first domino near the end of the ruler. Use a piece of masking tape to make a hinge connecting the back of the domino to the ruler. Figure 1A shows what tape hinges should look like.
- ❹ Place the second domino on the ruler about three-quarters of a domino's length from the first domino.
- ❺ Connect the second domino to the ruler with a tape hinge like you did in step 3.

- ⑥ Attach the remaining 6 dominoes in the same way.
- ⑦ Cut 8 more strips of masking tape, each about the length of a domino.
- ⑧ Use these pieces of tape to reinforce the hinges. Wrap each piece of tape around the ruler and the base of the tape hinge. The hinges shown in Figure 1B are reinforced in this way.

Exploring with the Model

- ① Place the ruler flat on your desk, and make sure all the dominoes are upright. If necessary, turn the ruler so that the faces of the dominoes are facing you.
- ② Flick the first domino with your finger to make it fall. Watch and record what happens.
- ③ Repeat step 2. What do you have to do before you can flick the dominoes again?
- ④ Make the dominoes fall several more times and closely observe their reaction each time. Do they all fall at the same speed? Can you make them fall in the reverse direction? Record your observations.
- ⑤ Reset the dominoes so that they are upright. Barely touch the first domino with your finger. Record what happens. Do this again several times, using slowly increasing amounts of force on the first domino. Record your observations.
- ⑥ Remove one domino from the middle of the ruler. Reset the dominoes so that they are on end. Flick the first domino. What happens?

Interpreting Observations

Compare the response of the dominoes when the first one in the line is just barely touched to when you used significant force to flick it. Can you think of a way this models our ability to perceive different stimuli (touch, smell, dim light, etc.)? Hint: Is there a minimum strength of stimulus we need to feel a feather touching our arm? When the dominoes all fall, do they reset themselves? What must happen for them to be in the starting position again? Hypothesize how this might represent something comparable to the way our nervous system functions. When a domino is removed from the center of the line, what happens when you do the exploration? Can you think of any disease or disorder that this might model?

The Domino Effect

Materials

for each individual or pair

- ▲ ruler, 30 cm or longer
- ▲ 8 dominoes (standard, wooden)
- ▲ masking tape
- ▲ scissors
- ▲ paper for recording observations

Management

- ▲ Amount of time for the activity:
30–40 minutes
- ▲ Preparation time: 10 minutes to set
out materials
- ▲ Group size: 1–2

Preparation and Setup

Activity Overview

Construct a simple device that models several important aspects of the way a nerve impulse is propagated from dendrite to axon.

Concepts

- › Nerve cells are called neurons.
- › Neurons require a stimulus of a minimum strength to fire.
- › The nerve impulse is propagated along the length of the nerve cell.
- › After a neuron has fired, there is a refractory period during which it cannot fire.
- › Neurons use energy to reset their resting state so that they can fire again.

Preparation

None, except for obtaining materials.

Questions for Getting Started

- › Has your doctor ever checked your reflexes by tapping your knee with a hammer? What happens? What do you think is wrong if your knee doesn't jerk?
- › What is your spinal cord and what does it do?

TIP!

- If time is short, you can prepare the models ahead of time, or you can construct a single, larger model on a meterstick and use it for a demonstration of nerve impulse propagation.

After the Exploration

Expected Results

When the first domino is toppled, it begins a chain reaction in which each subsequent domino is toppled until there are no more dominoes to topple. This chain reaction has certain properties that can be related to the propagation of an impulse along the membrane of a neuron: The first domino must be pushed a certain distance before it will fall; the pulse of falling dominoes moves at a constant speed without losing energy as it travels; the pulse travels in one direction only; dominoes fall in an all-or-nothing fashion; energy must be used to reset the dominoes between each trial.

What's Going On?

Each property of the model noted above is analogous to an important aspect of neuron function:

- › The first domino will not fall until it is pushed beyond a critical angle; in a similar way, a nerve impulse will not be triggered until the nerve is excited beyond its firing threshold. The threshold phenomenon can be seen in the operation of our sensory nerves: we cannot hear very faint sounds, for example, because the stimulus is not strong enough to excite the auditory nerve.
- › Once the pulse of falling dominoes begins to propagate, it moves at a constant speed independent of the size of the starting push; analogously, the speed of the propagation of a nerve impulse is independent of the size of the triggering signal.
- › The domino pulse does not lose energy as it propagates because the potential energy of each standing domino is released as kinetic energy when the domino falls; similarly, nerve impulses do not lose energy as they propagate.
- › The domino pulse travels in only one direction; likewise, nerve impulses can travel only in the dendrite-to-axon direction.
- › The dominoes cannot fall again until they are reset, which requires an input of human energy. In the same way, the nerve cell uses energy to redistribute ions and re-establish the resting state after a nerve impulse has propagated down the axon, and the nerve cannot fire again until this occurs.

The removal of a domino from the ruler models the effects of the disease multiple sclerosis. Just as the pulse of tumbling dominoes stops when it reaches the gap in the center of the ruler, a nerve impulse stops when it reaches a portion of a neuron damaged by multiple sclerosis.

The axons of neurons in the peripheral nervous system (sensory and motor neurons) are coated with a material called myelin. Myelin acts as an insulator similar to the nonconductive coatings of electrical wires. The insulation provided by myelin greatly increases the rate of conduction of nerve impulses. Unmyelinated nerves conduct impulses at about 1 mile per hour (0.5 m/s), but myelinated nerves transmit impulses at about 200 miles per hour (120 m/s).

In multiple sclerosis, the myelin sheaths are broken down, creating gaps in the myelin similar to holes in the insulation surrounding an electrical wire. These gaps interrupt the propagation of nerve impulses.

The removal of a domino also mimics the effects of a severe nerve or spinal cord injury. A nerve impulse cannot propagate past the site of the injury, just as the pulse of falling dominoes is stopped by the missing domino.

Discussion Questions

- ❶ Why do you think nerve impulses travel in only one direction?
- ❷ Do we feel everything that touches us? What are some things that might touch us that we don't feel? How would you explain this observation using the model?
- ❸ Sometimes people become paralyzed due to injuries from serious automobile or motorcycle accidents. What do you think causes the paralysis? Can you use the domino model to explain the reason for the paralysis?

Going Further: Ideas for Inquiry

- › Find out how nerve impulses are transmitted between individual neurons, across the gap called the synapse. Explain how the dominoes can model this process as well.
- › There are sounds you can't hear because they aren't strong enough to trigger the neurons in your inner ear. In the same way, there are tastes you can't taste, aromas you can't smell, and touches you can't feel. How strong does a stimulus have to be to trigger the neurons that allow you to experience touch, sight, sound, taste, and smell? Design some experiments to test the threshold level of the stimuli for one or more of your senses.

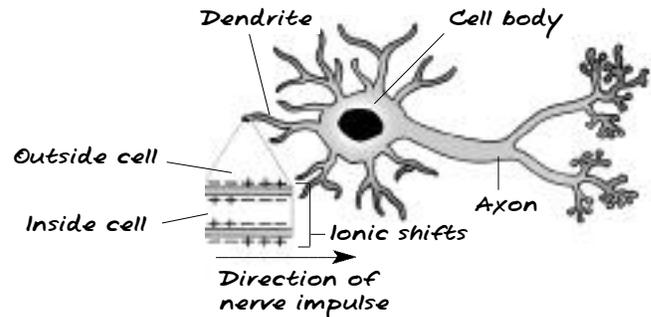


Figure 2: Changes in ions across a nerve cell membrane

The Basics and Beyond

Background

Nerve cells, or neurons, make up the information highways of the body. The job of most individual neurons is to pick up signals from neighboring neurons and transmit them to another neuron or to a target cell.

A neuron has three major regions: branched projections called dendrites; a central portion, the cell body, which contains the cell nucleus; and a single long projection called the axon (see Figure 2).

In a neuron at rest, the concentration of negative ions inside the neuron is greater than the concentration outside, creating a difference in charge across the neuron's plasma membrane. This difference in charge is called the membrane potential.

A sufficiently strong stimulus to the dendrite of a neuron initiates a nerve impulse. The impulse begins as an exchange of ions across a localized area of the plasma membrane, which reverses the polarity of the membrane potential there. This change is an all-or-nothing response and does not vary in intensity. This reversal of polarity causes the same change in the neighboring area of the membrane, which causes a reversal of polarity further along, and so on. In this way, the impulse propagates along the length of the neuron as a cascade of ionic exchanges. It does not lose energy as it travels because it is continually regenerated at each new site along the membrane. The impulse travels to the neuron's axon, which passes the signal on to another neuron or to a target cell by releasing chemicals called neurotransmitters.

Tidbit

► Axons can be very long—up to a meter in the case of a neuron that reaches from the big toe to the base of the spinal cord.