



The Boltzmann Distribution

Lee Marek

Topic

Distribution of kinetic energy



Time

30 minutes



Safety

Please click on the safety icon to view the safety precautions.
Remember to wear safety goggles.

Materials

FOR SCHOOL

200 kernels of popcorn
1,000-mL or 1,500-mL tall form
beaker
25–30 mL cooking oil
burner
ring stand
metal screen
aluminum foil
stopwatch or a clock with a
second hand
graph paper

FOR HOME

400 kernels of popping corn (50 mL)
3-L pot at least 10 cm high (glass
works best) with a tight-fitting lid
15 mL cooking oil
stove or electric burner
graph paper
felt-tip pen
stopwatch or a clock with a
second hand

Procedure

FOR SCHOOL

1. Choose a partner for this experiment.
2. Divide an 8¹/₂ × 11 plain sheet of paper into boxes for a timing grid, as shown in the data table.
3. Pour 25 to 30 mL oil into the beaker. Use new beakers and save them for this lab alone to avoid contamination.
4. Cover the metal screen with three pieces of aluminum foil to spread out the heat on the beaker bottom.

DATA TABLE			
Each box represents 15 sec			
0–15 sec	16–30 sec	31–45 sec	46–60 sec
1–1:15	1:16–1:30		

- Place the beaker on the screen, and make sure it is level and that the burner is centered under it. Heat the beaker.
- Put one kernel of popcorn in the hottest part of the oil. When it pops, add the rest. Cover the beaker with a piece of aluminum foil with a small hole in the center, and secure the foil.
- Start timing when the next kernel pops. Record the number of pops that occur in 15-sec intervals. One person should call out the time intervals while the other puts dots in the timing grid for each pop. Since the kernels pop fast, you may have to estimate the pops for some time periods.

FOR HOME

- Using a plain sheet of paper, divide it into a timing grid as shown in the data table.
- Place oil and popping corn in the cooking pot, cover the pot, and cook over medium heat.
- Listen carefully. Start timing when you hear the first pop. Have a friend begin counting 15-sec intervals. Begin with the first square; record the number of pops that occur in 15 sec by placing a dot in the box for each pop heard. At the end of 15 sec, move to square 2 and repeat the procedure. (When corn is popping quickly, each pop is hard to hear, so you will have to estimate.)
- Count the number of dots in each box, and graph the results. Draw as smooth a curve as you can, showing the point distribution. The graph is a plot of the number of pops in an interval as a function of time. For better data, repeat the whole procedure a few times. Make all the graphs, and then make a graph of the average number of pops in each box of the same number.
- Relate the graph shape to a Boltzmann distribution.
- Where does the analogy break down? Hint: What would the popcorn curve look like if the popcorn were heated in a hotter flame (higher temperature)?
- What causes the popcorn to pop?
- Why didn't all the kernels pop at once?

┌ What's Going On

Corn pops because the water contained within a kernel boils and turns into water vapor, which is under pressure and explodes the kernel. As you heat the popcorn, you move the heat distribution of the kernels to hotter temperatures. As the distribution moves past the boiling point of water, first the kernels on the right end of the curve pop, then those in the middle, and finally those at the left end, thus producing the few-many-few pattern. Imagine that the X axis represents kinetic energy, with higher values as you move to the right, and that the curve represents the number of particles at each energy. Then the dotted line corresponds to the average kinetic energy, or the heat of the substance, which we measure as temperature. If you cool the substance, the whole curve moves to the left, indicating cooler temperature and a lower distribution of kinetic energies. If you heat the substance, the curve moves to the right. The kinetic energy distribution moves past the boiling point of water (the dashed line).

┌ Connections

Temperature is the average kinetic energy of the particles that make up a substance. *Kinetic energy* is the energy a particle has because of its mass and the speed at which it zips around in space. In any substance, some particles have more kinetic energy than the average; some have less. If you could stack up all the particles whizzing about with the same kinetic energy, and compare all the different stacks, you would be examining the distribution of kinetic energy in a substance. The distribution of kinetic energy in a substance is known as the *Boltzmann distribution*. In this demonstration you discovered the shape of the curve of a Boltzmann distribution.

Safety Precautions

READ AND COPY BEFORE STARTING ANY EXPERIMENT

Experimental science can be dangerous. Events can happen very quickly while you are performing an experiment. Things can spill, break, even catch fire. Basic safety procedures help prevent serious accidents. Be sure to follow additional safety precautions and adult supervision requirements for each experiment. If you are working in a lab or in the field, do not work alone.

This book assumes that you will read the safety precautions that follow, as well as those at the start of each experiment you perform, and that you will *remember* them. These precautions will not always be repeated in the instructions for the procedures. It is up to you to use good judgment and pay attention when performing potentially dangerous procedures. Just because the book does not always say “be careful with hot liquids” or “don’t cut yourself with the knife” does not mean that you should be careless when simmering water or stripping an electrical wire. It *does* mean that when you see a special note to be careful, it is extremely important that you pay attention to it. If you ever have a question about whether a procedure or material is dangerous, stop to find out for sure that it is safe before continuing the experiment. To avoid accidents, always pay close attention to your work, take your time, and practice the general safety procedures listed below.

PREPARE

- Clear all surfaces before beginning work.
- Read through the whole experiment before you start.
- Identify hazardous procedures and anticipate dangers.

PROTECT YOURSELF

- Follow all directions step by step; do only one procedure at a time.
- Locate exits, fire blanket and extinguisher, master gas and electricity shut-offs, eyewash, and first-aid kit.
- Make sure that there is adequate ventilation.
- Do not horseplay.
- Wear an apron and goggles.
- Do not wear contact lenses, open shoes, and loose clothing; do not wear your hair loose.
- Keep floor and work space neat, clean, and dry.
- Clean up spills immediately.
- Never eat, drink, or smoke in the laboratory or near the work space.
- Do not taste any substances tested unless expressly permitted to do so by a science teacher in charge.

USE EQUIPMENT WITH CARE

- Set up apparatus far from the edge of the desk.
- Use knives and other sharp or pointed instruments with caution; always cut away from yourself and others.
- Pull plugs, not cords, when inserting and removing electrical plugs.
- Don’t use your mouth to pipette; use a suction bulb.
- Clean glassware before and after use.
- Check glassware for scratches, cracks, and sharp edges.
- Clean up broken glassware immediately.

- Do not use reflected sunlight to illuminate your microscope.
- Do not touch metal conductors.
- Use only low-voltage and low-current materials.
- Be careful when using stepstools, chairs, and ladders.

USING CHEMICALS

- Never taste or inhale chemicals.
- Label all bottles and apparatus containing chemicals.
- Read all labels carefully.
- Avoid chemical contact with skin and eyes (wear goggles, apron, and gloves).
- Do not touch chemical solutions.
- Wash hands before and after using solutions.
- Wipe up spills thoroughly.

HEATING INSTRUCTIONS

- Use goggles, apron, and gloves when boiling liquids.
- Keep your face away from test tubes and beakers.
- Never leave heating apparatus unattended.
- Use safety tongs and heat-resistant mittens.
- Turn off hot plates, bunsen burners, and gas when you are done.
- Keep flammable substances away from heat.
- Have a fire extinguisher on hand.

WORKING WITH MICROORGANISMS

- Assume that all microorganisms are infectious; handle them with care.
- Sterilize all equipment being used to handle microorganisms.

GOING ON FIELD TRIPS

- Do not go on a field trip by yourself.
- Tell a responsible adult where you are going, and maintain that route.
- Know the area and its potential hazards, such as poisonous plants, deep water, and rapids.
- Dress for terrain and weather conditions (prepare for exposure to sun as well as to cold).
- Bring along a first-aid kit.
- Do not drink water or eat plants found in the wild.
- Use the buddy system; do not experiment outdoors alone.

FINISHING UP

- Thoroughly clean your work area and glassware.
- Be careful not to return chemicals or contaminated reagents to the wrong containers.
- Don't dispose of materials in the sink unless instructed to do so.
- Wash your hands thoroughly.
- Clean up all residue, and containerize it for proper disposal.
- Dispose of all chemicals according to local, state, and federal laws.

BE SAFETY-CONSCIOUS AT ALL TIMES