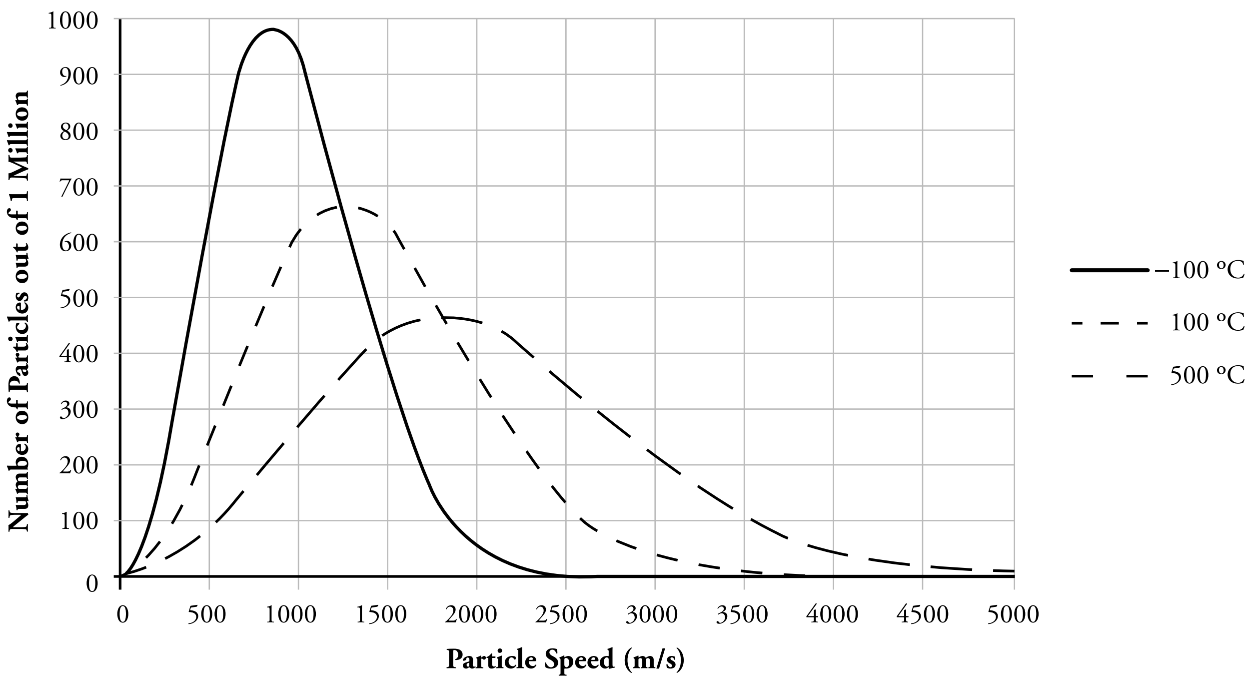
# Maxwell-Boltzmann Distributions

How does temperature change the speed of gas particles?

## Why?

When a sample of matter is heated, the particles speed up. But what does that mean? Are all the particles in a sample moving at the same speed? Do they all speed up equally? Does mass affect particle speed? Two scientists, James Maxwell and Ludwig Boltzmann, proposed an equation that could be used to predict the speeds of ideal gas particles (atoms or molecules) at any temperature. Their equation is based on statistics and thermodynamic relationships. It is used by chemists and physicists to predict properties of gases such as pressure and diffusion rates, and it can be used to predict rates of reactions involving gases.

## Model 1 – Helium at Different Temperatures




1. Consider the graph in Model 1.
   *a.* What is the variable and unit of the *x*-axis?

   *b.* Particles of what substance are represented in the graph?

   *c.* How many particles are represented in the graph?

   *d.* What temperatures are represented in the graph?

2. According to Model 1, do all of the gas particles in a sample move at the same speed for a given temperature? Justify your answer with evidence from Model 1.

3. According to Model 1, approximately how many gas particles in the sample are traveling 1000 meters per second?

   *a.* at –100 °C?

   *b.* at 100 °C?

   *c.* at 500 °C?

4. According to Model 1, approximately how many gas particles in the sample are traveling 2500 meters per second?

   *a.* at –100 °C?

   *b.* at 100 °C?

   *c.* at 500 °C?

5. Explain why the 500 °C curve is flatter in Model 1 than the –100 °C curve.

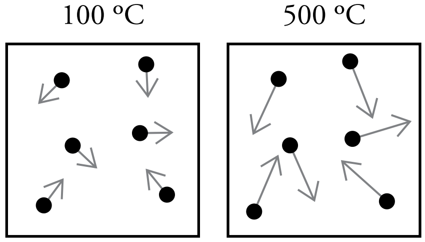
6. At what temperature are the helium particles in the sample moving the slowest on average?

7. At what temperature are the helium particles in the sample moving the fastest on average?

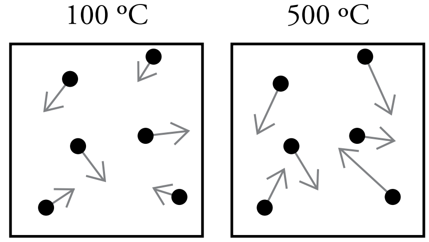
8. When a sample of gaseous matter is heated, do all of the particles in the sample speed up? Justify your answer with evidence from Model 1.

9. Circle the set of drawings below that more accurately illustrates the difference in particle speeds for particles of helium at 100 °C and 500 °C? Justify your reasoning. *Hint:* The longer the arrow, the faster the particle is moving.

100 ºC 500 ºC

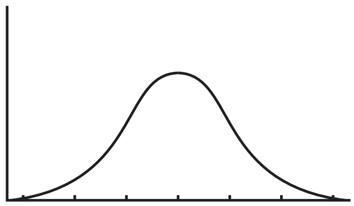


100 ºC 500 ºC

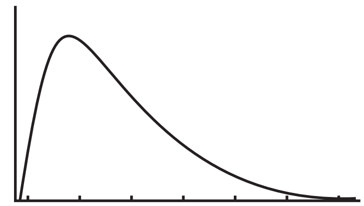


## Read This!

The distribution curves in Model 1 are based on the mathematical equation developed by Maxwell and Boltzmann. Their shape is generally a bell curve, but they are skewed to the right.



Normal bell curve



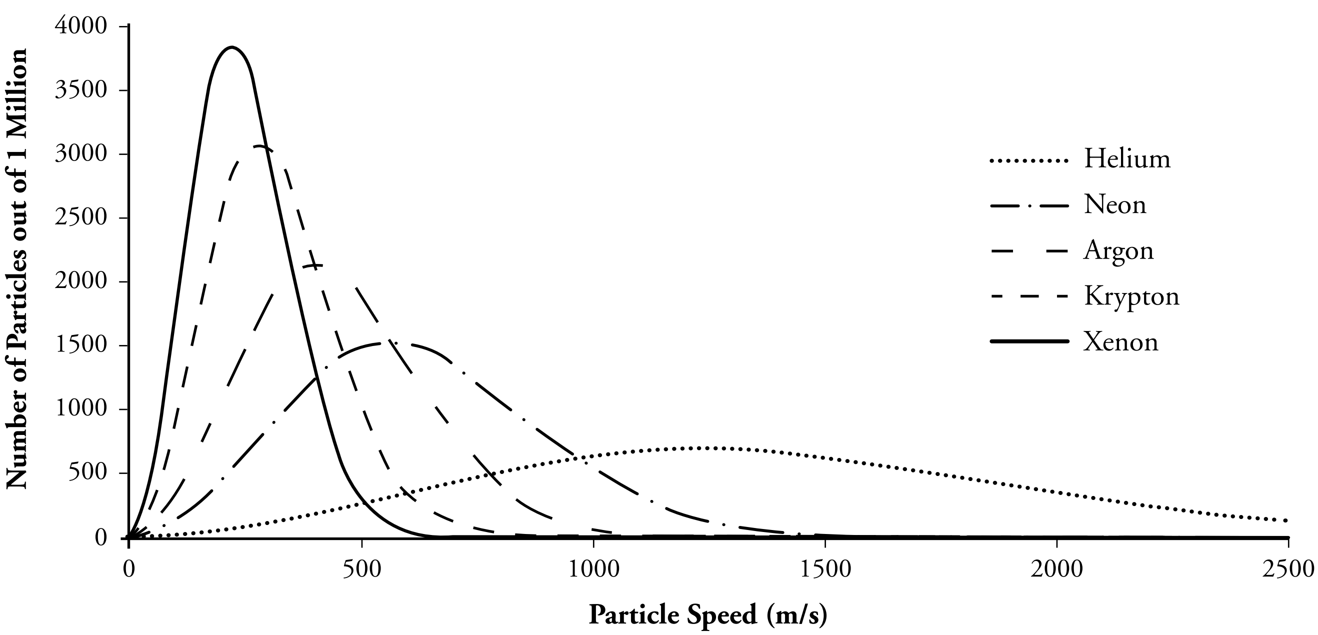
Right-skewed bell curve

Bell curves are used by mathematicians to model the properties of large groups of things. There will always be some variation to the property, but values in the middle of that range tend to be exhibited more often by members of the group than the extremes. On a normal bell curve, the average value is also the value exhibited by the group most often. The left edge of Maxwell-Boltzmann distributions are limited by a speed of zero—particles cannot have negative speeds. The right edge, however, can extend to very high speeds—theoretically to infinitely high speeds. This causes the distribution to be skewed. The average value is not necessarily the value that is exhibited by the group most often.

10. Describe how the distribution curve for the speeds of particles in a sample changes as the sample is heated.

11. Predict the distribution curve for a sample of helium at a temperature of 800 °C. Draw this curve on Model 1.

## Model 2 – Noble Gases at 100 °C



12. List the noble gases that are represented in the graph in Model 2 with their average atomic masses.

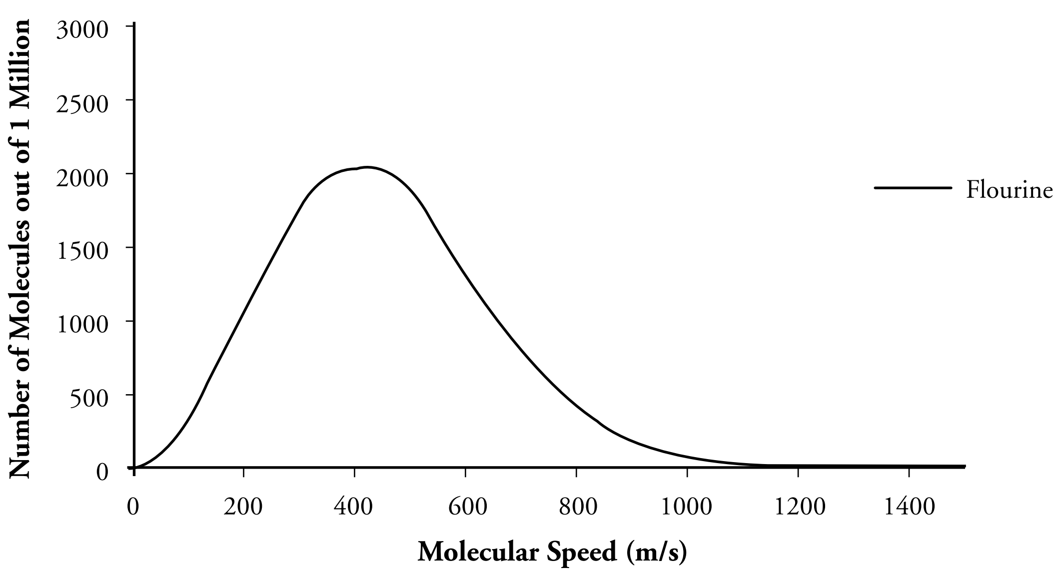
13. Which variable explains the difference in distribution curves for the different noble gases in Model 2—temperature or mass? Explain your reasoning.

14. Which noble gas has the slowest average particle speed at 100 °C?

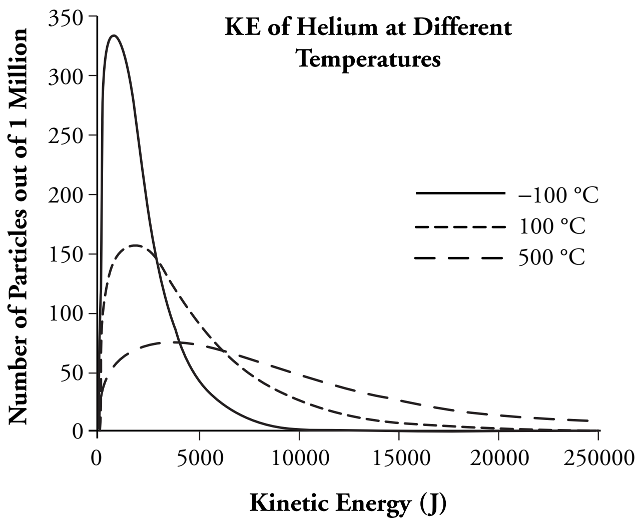
15. Which noble gas has the fastest average particle speed at 100 °C?

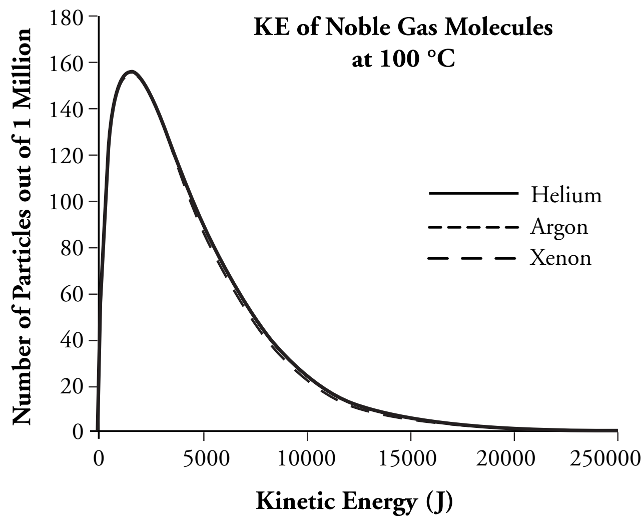
16. In a complete sentence, describe the relationship between the molar mass of particles in a sample and the average particle speed at a given temperature.

17. Consider the distribution curve below for fluorine gas ($F_2$) at 100 °C. Sketch an approximate distribution curve for chlorine gas ($Cl_2$) at 100 °C on the same graph.



## Model 3 – Kinetic Energies




18. What is the variable and unit of the *x*-axis for both of the graphs in Model 3?

19. What variable, temperature or molar mass, is being varied in the graph on the left?

20. What variable, temperature or molar mass, is being varied in the graph on the right?

21. Describe the relationship between the average kinetic energy of the particles in a sample and the temperature when the molar mass is held constant. Use a grammatically correct sentence.

22. Describe the relationship between the average kinetic energy of the particles in a sample and the molar mass when the temperature is held constant. Use a grammatically correct sentence.

23. Compare and contrast the graph on the left in Model 3 with the graph in Model 1.

24. Compare and contrast the graph on the right in Model 3 with the graph in Model 2.

25. The kinetic energy of a particle in a sample can be calculated by the following equation:

$$KE = \frac{1}{2} mv^2$$

where *m* stands for the mass of the particle and *v* stands for the particle speed.

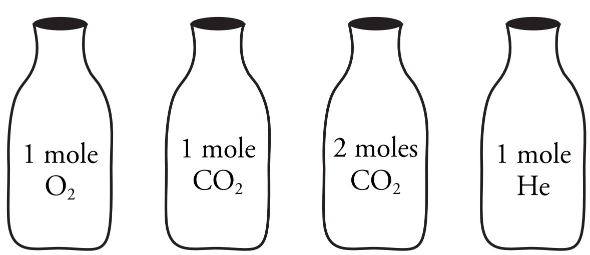
*a.* Use the equation above to explain the variation in the distribution curves in the graph on the left in Model 3.

*b.* Use the equation above to explain the lack of variation in the distribution curves in the graph on the right in Model 3.

26. Draw particulate representations of helium atoms at the two different temperatures below. Use arrows to illustrate the distributions in kinetic energies.

27. Draw particulate representations of two different noble gases at the same temperature below. Use arrows to illustrate the distributions in kinetic energies.

28. A student is presented with four bottles containing different gases. All samples are at the same temperature.

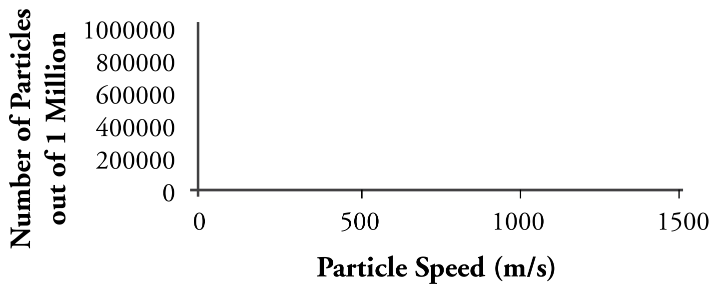



*a.* Which gas sample has the fastest average particle speed?

*b.* Which gas sample has the highest average kinetic energy?

## Extension Questions

29. Theoretically, what would the distribution curve for particle speeds look like for any gas at absolute zero?




30. In Question 28, one of the four bottles contained 2 moles of gas rather than 1 mole. Describe how this might change the gas sample behavior in terms of particle speed distribution, kinetic energies of the particles, pressure on the sides of the bottle and mean free path—the average distance a particle travels before colliding with another particle in the sample.

31. The activation energy for a chemical process is the minimum energy needed for a successful reaction to occur. This might be the energy needed to break a bond in a reactant molecule or to ionize a key component in the reaction. The speed with which the reaction occurs is a direct correlation to how many particles in the sample have the minimum energy. Use a Maxwell-Boltzmann distribution to illustrate why raising the temperature of a reactant mixture often speeds up the reaction.

32. Use a Maxwell-Boltzmann distribution to illustrate how adding a catalyst (lowering the activation energy) to a reaction speeds up the reaction rate.