

**BLOSSOMS Interactive Video Lecture:
Temperature, Pressure and American Football: Introduction to Gay-Lussac's Gas Law**

Student Worksheet (with answers)

(Activity 2)

Define: what is temperature?

Temperature, when measured in Kelvin, is a number that is directly proportional to the average kinetic energy of the molecules in a gas.

Define: what is pressure?

Pressure is force per unit area, and is a measure of the force that the molecules of a gas exert on the container holding the gas.

Write Gay-Lussac's Gas Law and explain briefly what it means:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

For a fixed volume of gas, the ratio of absolute pressure to absolute temperature is constant.

(Activity 3) Three footballs (A, B, and C) are inflated to 12.5 PSI relative pressure in a laboratory that has a temperature of 74 degrees F. Football A is moved to a cooler with dry ice that is held at -13 degrees Fahrenheit; Football B is kept in the laboratory at a temperature of 74 degrees Fahrenheit; and Football C is moved to an oven that is lightly heated to a temperature of 102 degrees Fahrenheit. Use Gay-Lussac's Law to predict the relative pressure for each of the three footballs after sufficient time has elapsed for them to equilibrate to the new environments. Be careful to use absolute temperature and pressure values.

For all three footballs, the initial absolute pressure is $12.5 + 14.7 = 27.2$ PSI
For all three footballs, the initial absolute temperature is 296.6 Kelvin

The initial temperature for all three footballs in the laboratory is 296.6 Kelvin
The new temperature for football A is 248.2 Kelvin
The new temperature for football C is 312.0 Kelvin

For football A, the predicted relative pressure from Gay-Lussac's Gas Law is:
$$P_2 = 27.2 * (248.2 / 296.6) - 14.7 = 8.06 \text{ PSI}$$

For football B, since the temperature does not change, the predicted pressure is the same:
$$P_2 = 12.50 \text{ PSI}$$

For football C, the predicted relative pressure from Gay-Lussac's Gas Law is:
$$P_2 = 27.2 * (312.0 / 296.6) - 14.7 = 13.91 \text{ PSI}$$

(Activity 4) In the 2015 AFC Championship game held on January 18th, 2015, the twelve footballs for the New England Patriots were measured before the game by the referee to be 12.5 PSI in a locker room that was approximately 71 degrees Fahrenheit. The referee used one of two different gauges to measure the footballs before the game – either the Logo gauge or the Non-Logo gauge. The field temperature that day was 48 degrees Fahrenheit. Use Gay-Lussac's Law to predict the on-field pressure level for the Patriots' footballs for the game.

The initial temperature in the locker room before the game was 294.8 Kelvin
The on-field temperature during the game was 282.0 Kelvin

The predicted pressure using Gay-Lussac's Gas Law is

$$P_2 = 27.2 * (282.0 / 294.8) - 14.7 = 11.32 \text{ PSI}$$

(Activity 5) After one of the footballs was intercepted by the other team during the first half of the football game, someone made an accusation of cheating – that the footballs may have been illegally deflated, allegedly giving the Patriots a competitive advantage. Therefore, at the start of halftime, the league decided to measure each of the remaining eleven Patriots' footballs with each of the two gauges (the Logo gauge and the Non-Logo gauge). Compute the average of the eleven pressure values for the Patriots' footballs that were measured with the Logo gauge: 11.80, 11.20, 11.50, 11.00, 11.45, 11.95, 12.30, 11.55, 11.35, 10.90, 11.35 PSI

The average of these eleven values is 11.49 PSI

(Activity 6) Compare your prediction from Gay-Lussac's Gas Law for the Patriots' footballs with the average of the eleven measurements from the Logo gauge. If the referee used the Logo gauge before the game to measure the Patriots' footballs, do you think that the Patriots' footballs were illegally deflated before the game?

The measured values are 0.17 PSI *higher* than the value predicted from Gay-Lussac's Law.

The students can decide themselves if this signifies evidence for tampering.

(Activity 7) Compute the average of the eleven pressure values for the Patriots' footballs that were measured with the Non-Logo gauge: 11.50, 10.85, 11.15, 10.70, 11.10, 11.60, 11.85, 11.10, 10.95, 10.50 and 10.90 PSI. If the referee used the Non-Logo gauge before the game to measure the Patriots' footballs, do you think that the Patriots' footballs were illegally deflated before the game?

The average of these eleven values is 11.11 PSI. The measured values with the Logo gauge are 0.21 PSI lower than the prediction from Gay-Lussac's Law.

(Activity 8) Discuss some of the sources of error and how this might affect your conclusions.

There are many potential sources of error, which include uncertainty in the starting temperature, the on-field temperature, the unknown measurement times, the potential effect of the footballs being wet, the effect of the balls being kept in a bag before being measured, potential drift in the calibration of the gauges, and so on.

(Activity 9) Suppose that the difference between the measured pressures and the values predicted from Gay-Lussac's Law were due to tampering. What percentage of air would need to be removed from (or added to) the footballs to achieve the difference between the average measurement and the predicted pressure based on Gay-Lussac's Gas Law? Hint: use the Ideal Gas Law, $PV=nRT$, and assume that the Temperature and Volume are constant.

If we assume that the volume V and temperature T are constant, then the percentage change in the number of moles of gas n required to achieve a given reduction in pressure Δp , is given by dividing the change in pressure by the total pressure (27.2 PSI).

A reduction of 0.21 PSI corresponds to a $0.21/27.2 = 0.0077$ reduction in the amount of gas, which corresponds to removal of less than 1% of the air.