Temperature, Pressure, and American Football: Introduction to Gay-Lussac's Gas Law Teachers Guide

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This lesson provides an introduction to Gay-Lussac's Gas Law, using as an example the Deflategate controversy that took place in the sport of American Football in 2015. The 2015 NFL AFC Championship game took place in Foxborough, Massachusetts on January 18th, 2015. That day, the New England Patriots defeated the Indianapolis Colts by a score of 45-7. The Patriots were alleged to have illegally deflated their footballs before the game, to gain an unfair competitive advantage. (It is alleged that deflated footballs would be easier to throw and catch, and less likely to fumble.) The league launched a legal and scientific investigation after the game, leading to a media firestorm. From a scientific perspective, at the heart of the story lies Gay-Lussac's Gas Law and the interpretation of measurements of temperature and pressure. This provides a great opportunity for students to apply critical thinking skills to an important real-world scenario – can the halftime measurements of the Patriots' footballs be explained by basic physical laws?

The main learning objectives of this BLOSSOMS interactive lesson are:

(1) to understand the concepts of temperature and pressure;

(2) to introduce the use of Kelvin (absolute) temperature measurement units, and to distinguish between absolute and relative (gauge) pressure measurements;

(3) to define Gay-Lussac's Law, and to use it to predict how the pressure of a fixed container of gas, such as a football, will change due to an increase or decrease in temperature;

(4) to compare predictions from a physical law with experimental measurements of the same quantity;

(5) to introduce the concept of measurement error and to discuss sources of uncertainty in pressure and temperature measurements;

(6) to use the Ideal Gas Law to compute the amount of gas that would need to be added or removed from a fixed volume of gas, held at constant temperature, to achieve a given increase or decrease in pressure.

This lesson has no pre-requisites, other than arithmetic and a basic knowledge of the behavior of gases that students should have acquired in middle school. The lesson should take students about an hour to complete. More time will be needed if you are able to perform your own cooling or heating experiment in the classroom, using one or more footballs or other sports balls, such as a soccer ball, matching our activity 3 in the video.

A simplified timeline of the events on January 18th, 2015 is as follows:

- Several hours before the AFC Championship Game, Referee Walt Anderson performed a pre-game inspection of the twelve Patriots' footballs in the Officials Locker Room at Gillette Stadium, and

verified that the footballs had a gauge (relative) pressure of 12.5 psi. He measured the footballs using one of two similar gauges that he owned – these are referred to as the "Logo gauge" and the the "Non-Logo gauge", because one had a Wilson logo sticker on it and the other did not. The temperature in the Officials Locker Room was approximately 71 degrees Fahrenheit.

- The Patriots' footballs were then brought to the playing field, where the on-field temperature was approximately 48 degrees Fahrenheit.
- During the first half of the game, one of the Patriots' footballs was intercepted by the other team. On the sideline, a member of the Colts measured the pressure of the football, and found that it was below the minimum 12.5 psi specification, and informed league officials that the footballs seemed to be underinflated.
- At the start of the halftime, the league measured each of the eleven remaining Patriots' footballs using each of the two gauges owned by Referee Walt Anderson. The measured values were as follows:

Football	Logo Gauge (psi)	Non-Logo Gauge (psi)
1	11.80	11.50
2	11.20	10.85
3	11.50	11.15
4	11.00	10.70
5	11.45	11.10
6	11.95	11.60
7	12.30	11.85
8	11.55	11.10
9	11.35	10.95
10	10.90	10.50
11	11.35	10.90

In its scientific investigation, the league concluded that *"within the range of likely game conditions and circumstances studied, they could identify no set of credible environmental or physical factors that completely accounts for the Patriots halftime measurements."*[1] This led to a ruling by NFL Commissioner Roger Goodell that Patriots quarterback Tom Brady *"participated in a scheme to tamper with the game balls"* and punished him with a four-game suspension.[2] During testimony at a hearing held by the league on June 23, 2015, league personnel admitted that, before this incident, they had no knowledge of the effect of temperature on the pressure of a football.[3] In this BLOSSOMS lesson, we aim to give your students the opportunity to "be the scientists" for this controversy, asking them to look at the measurements taken by the league, to compare them with predictions from Gay-Lussac's Gas Law, and to reach their own conclusions.

Our activity 1 involves putting an uninflated balloon on the end of a soda bottle, and then placing it first in a container of warm water, and then in a container of cold water. It helps to inflate and deflate the balloon a few times before you do this, to stretch it out. Note that in this activity, Gay-Lussac's Law does not

[1] The Wells Report, May 6, 2015
[2] Ruling by NFL Commissioner Roger Goodell, June 28, 2015
[3] Appeal hearing transcript, June 23, 2015

apply – for this scenario, the pressure is relatively constant, and instead temperature and volume are being changed. This illustrates Charles' Gas Law, which states that if pressure is constant, then the ratio of volume to temperature remains constant. We chose this activity to remind students of how a gas behaves, illustrating how the energy of gas molecules increases or decreases with rising or falling temperature.

In activity 2, we ask students to work together to define "what is temperature?" and "what is pressure?" Hopefully, this will generate some good discussions.

We then introduce Gay-Lussac's Law, and in activity 3, we ask students to use it to predict the new pressure level for three footballs – labeled A, B, and C – that we have in the lab. All three footballs were initially inflated to 12.5 psi, several hours before we started filming, in a room that was kept at a temperature of 74 degrees Fahrenheit. Subsequently, ball A was placed in a cooler with dry ice at a temperature of -13 degrees F. Ball B was kept in the 74 degree lab. And ball C was placed in an oven with light heat at 102 degrees Fahrenheit. In activity 3, we ask students to use Gay-Lussac's Law to predict the new pressure levels for each of the three footballs, after about an hour of time elapses.

If there is time in your class, it would be ideal if the students can inflate a sports ball to a desired pressure and measure it with a pressure gauge, while also recording the room temperature. And subsequently, then can place the ball in a colder environment, such as a refrigerator or a cooler, and/or a warmer environment, such as an oven set to low heat. In the video, we used dry ice to achieve a temperature of -13 degrees Fahrenheit in a cooler. (If you use dry ice, be careful to not get a dry ice burn.) In the video, we compare the predicted pressure values with actual measurements, and discuss the results.

In activity 4, we ask students to turn their attention to the conditions of the 2015 AFC Championship game, using Gay-Lussac's Law to compute the predicted on-field pressure for the Patriots' footballs during the game. In activity 5, we ask students to compute the average of the 11 measurements of the Patriots' footballs that were obtained at halftime using the Logo gauge. Referee Walt Anderson's best recollection is that he used the Logo gauge to verify the pressure levels of the footballs before the game.

In activity 6, we ask students to compare the prediction that they computed in activity 4 with the average of the measurements that they computed in activity 5, and to discuss the result.

In activity 7, we ask the students to repeat this process for the Non-Logo gauge measurements, computing the average of the Non-Logo values, comparing this against the gas law prediction, and discussing the result.

In activity 8, we ask the students to discuss some of the sources of uncertainty in the league's measurement process, and how this might affect their conclusions. Some of the sources of the uncertainty are the exact temperatures and times when measurements were taken, and the potential effect of some of the footballs being wet. It rained steadily throughout the game, and studies have shown that when a football is wet, the leather stretches. This causes the volume to increase, which results in a further drop in pressure.

Finally, in activity 9, we ask students to use the Ideal Gas Law to compute the percentage of air that would need to be removed (or added) from the footballs to achieve the difference between the prediction and the observations. Is this a significant amount of air? How does it compare against the sources of uncertainty in the various environmental factors? We hope that this can generate an interesting discussion in your class.