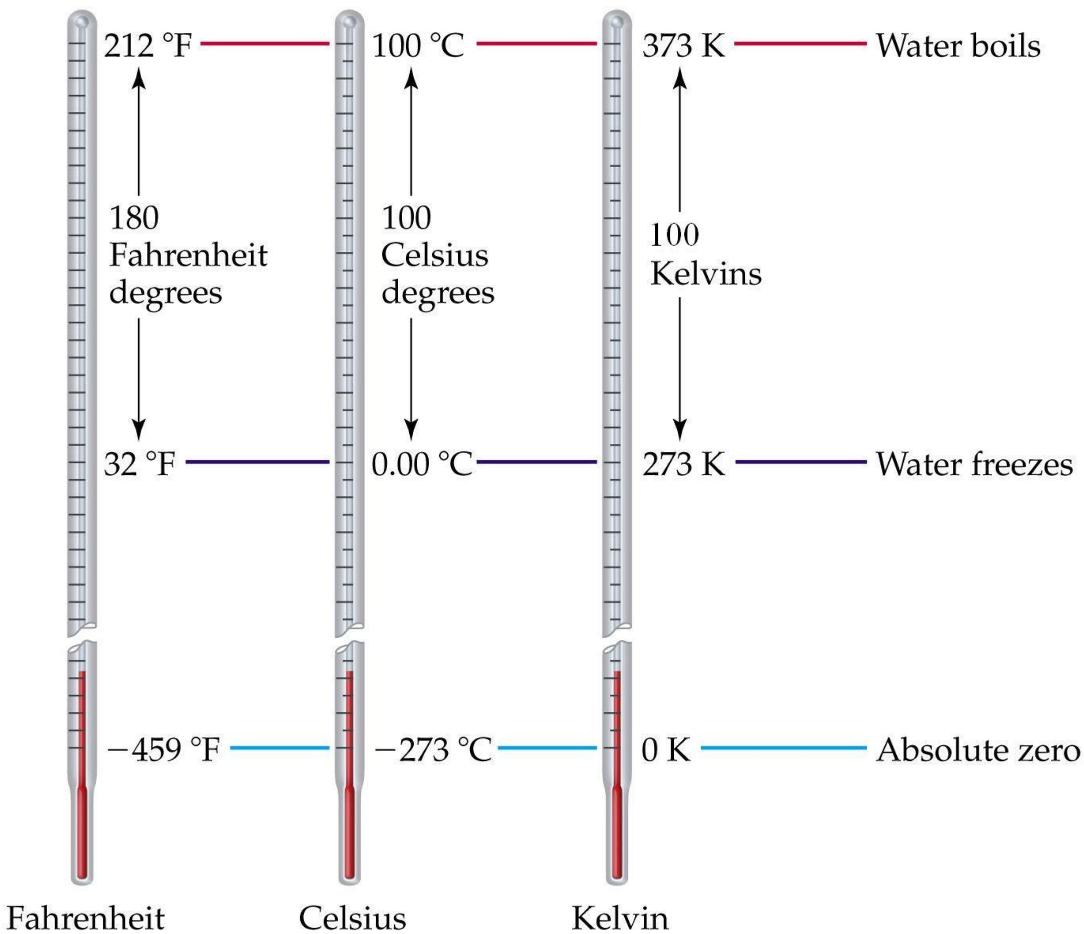
I. **Temperature, Pressure, and Density**

A. **Temperature: The microscopic kinetic energy of atoms and molecules, which vibrate and translate even in solids, so long as the temperature is above absolute zero.**

1. **At absolute zero, all microscopic motion ceases, and absolute zero is -273°C, or -459°F, and zero on the Kelvin absolute temperature scale.**

2. **Most of the world uses the Celsius or centigrade scale, which dates from the mid-1700s.**



B. a. The 1744 version utilized 2 fixed points, 0°C, the freezing point of impure water, and 100°C, water's boiling point, both of those at sea level. (Actually, Celsius' original version was inverted).

1. In the United States, we persist in using Daniel Gabriel Fahrenheit's temperature scale, invented in 1724.

a) In Fahrenheit's day, the challenge was to create instruments capable of making repeatable measurements, calibrated using common materials. (A mixture of ice, water, and ammonium chloride).

b) Fahrenheit lacks Celsius' clean and simple rationale, but you know what? It's curiously well suited to meteorology, if only accidentally. The temperatures of 0°F and 100°F, bracket the range of temperatures commonly encountered in temperate climates. I'll try to provide temperatures in Celsius and Fahrenheit, and big numbers we'll manipulate in Kelvin as well.

c) A warm day is 30°C or 86°F. A typical indoor temperature might be 20°C or 68°F. Freezing is 0°C and 32°F. Minus 40 is the same on both scales.

d) The Celsius scale is pegged to the boiling point of water, 100°C or 212°F, but that's the boiling point at sea level. As you ascend above sea level, boiling point decreases.

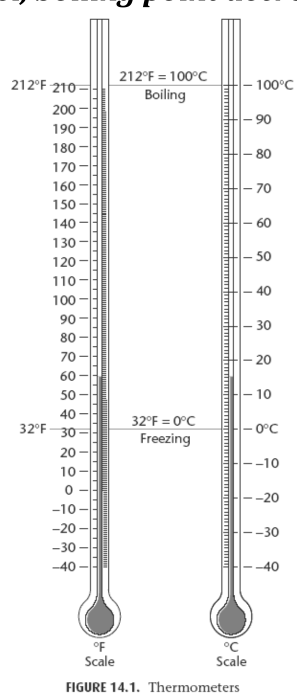


FIGURE 14.1. Thermometers

C. Pressure is force per unit area

1. In the atmosphere force is largely gravity, due to air's weight.

2. Sea level pressure is 15 pounds per square inch. (It's applying 15 pounds for every square inch of the Earth's surface). That's about half of the pressure you probably have in your automobile tire.

a) Average sea level pressure is also 30 inches of mercury.

b) Average sea level pressure is also 100,000 pascals. That's the official metric system unit, the pascal. It's 1000 hectopascals or 1000 millibars, the traditional unit used in meteorology and the unit I'll use through this course.

3. Pressure represents the weight of down-lying air and it's pressing downward due to gravity. Therefore, pressure decreases with height. As we ascend in the atmosphere, more of the mass of the atmosphere is below us and less is above, so the pressure pushing down on us decreases.

a) This means of a surface pressure of about 1000 millibars, somewhere above our heads the pressure is only 750 millibars, 500 millibars, above that, 250 millibars, and ultimately, zero millibars at the top of the atmosphere.

b) 99% of the mass of the atmosphere is beneath the 10-millibar level, and more than 99% of the weather. The average of the 10 millibar surface above our heads is 30 kilometers, or 18 miles, above sea level. (Relate that to the 6400 kilometers or 4000 miles of the Earth's radius)

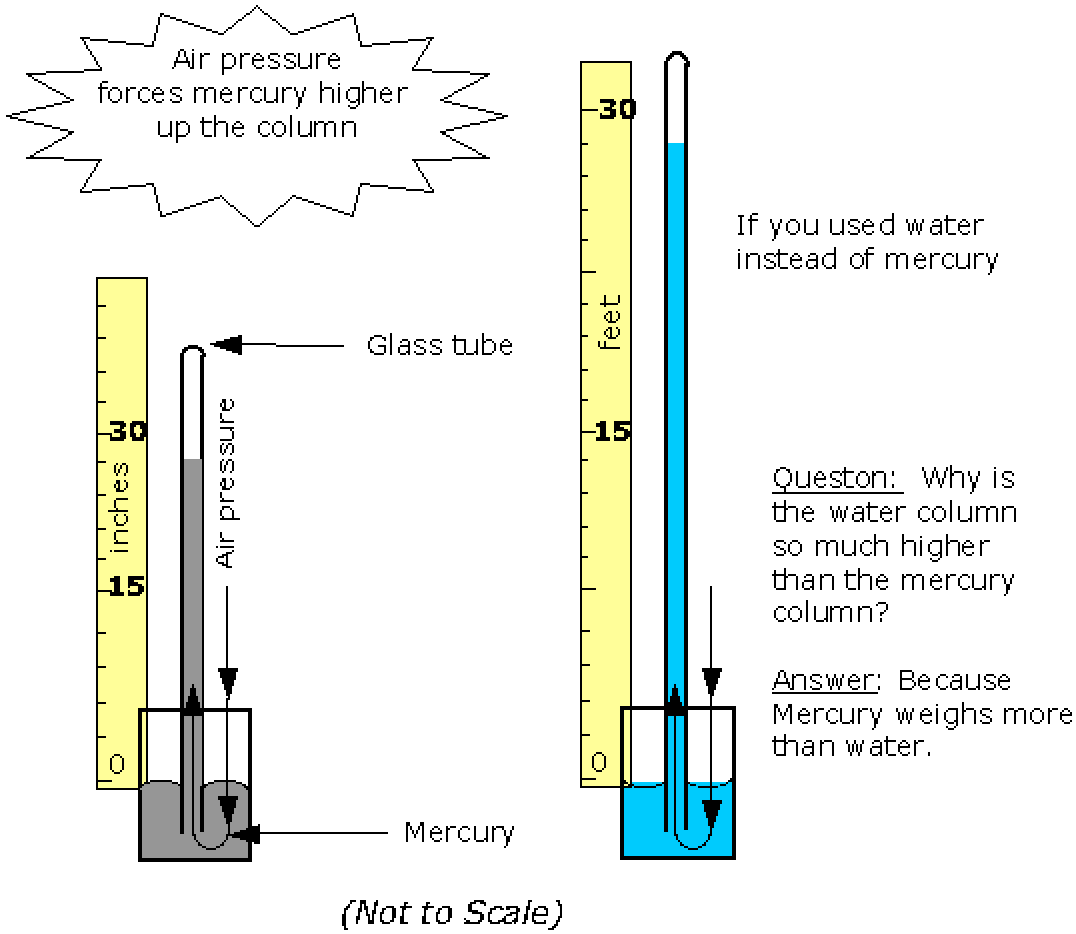
4. The barometer measures pressure in inches of mercury.

a) Picture a water well or a glass partially full of water. The atmospheric pressure is being exerted on the plain surface of that water. It's pushing down everywhere.

b) Now insert a tube or a straw, and notice the water does rise up a little bit, but that's due to surface tension. The water doesn't keep rising farther into the straw because there's also air in the tube, pushing down.

*c)	We want to get water out of that tube, so the first thing we have to do is get the air out by creating a vacuum.*

*d)	Once the vacuum is created, the atmosphere does the job of pushing water up into the tube from below. The difference between the top and the base of the fluid column indicates how much force exist, pressing down on the outside of the straw. [Force per unit area is pressure] We have created a barometer.*



e) ***At standard sea level pressure of 1000 millibars, the atmosphere can support a water column 33 feet, or 10 meter, high.***

f) ***If your well water is down deeper than that, suction alone cannot extract the water, and the reason is it isn't suction that was pulling the water up out of the well anyway----it was atmospheric pressure pushing down on the fluid surrounding the tube.***

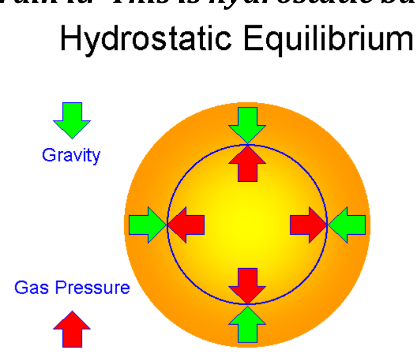
g) ***You can't put a 33 ft tube in your back pocket to measure the atmospheric pressure. In the 1600s, Evangelista Torricelli employed mercury, a liquid metal. Sea level pressure can support a mercury column about 30 inches high, hence the unit of pressure persists to this day.***

h) ***The barometer demonstrates the importance of pressure in generating motion of fluids such as water and air, but it was a pressure difference that is truly important.***

i) ***Nature wants to move mass form high to low pressure. Nature wants to move mass from high to low pressure, (from surplus to deficit). Nature responds to pressure differences by trying to eliminate them.***

j) ***If a fluid is not accelerating, like a liquid trapped inside a straw while it is sealed at the top by your finger, then the force must be balanced. The primary balance here is the pressure difference acting upward and the gravity force pulling down. This is a stalemate we call "hydrostatic balance."***

k) ***Hydrostatic balance is why we still have a atmosphere. There is a 500 millibar pressure drop in just 3.5 miles between the surface and midtroposphere. That makes a force so strong that only gravity can restrain it. This is hydrostatic balance.***



5. Air is very compressible. It's scrunched at the bottom near the surface, owing to its own weight. We may have 99% of the mass of the atmosphere below 18 miles, but 50% is in the lowest 3.5 miles, or 5.5 kilometers.

a) Pressure doesn't just decrease with height---it decreases exponentially with height. The average height of the 500 millibar level is only 3.5 miles above sea level.

b) Because of air's squeezability, something else also decreases with height: density.

D. Density is mass divided by volume.

1. In the metric system, the mass is kilograms and the volume is cubic meters, so it's kilograms per cubic meter.

a) Consider a box containing air or some other material. How would I change the density of stuff in that box? Well, I can cram more stuff into the box, or I can make the box with the same mass smaller. Either will increase the density.

b) For gases like air, temperature, pressure, and density are related through a simple, powerful equation, the ideal gas law:

$$P=\rho RT$$

(1) P is pressure, measured in pascals

(2) ρ, a Greek letter, is used for density. Kilograms per cubic meter are the units.

(3) T is temperature in the Kelvin scale

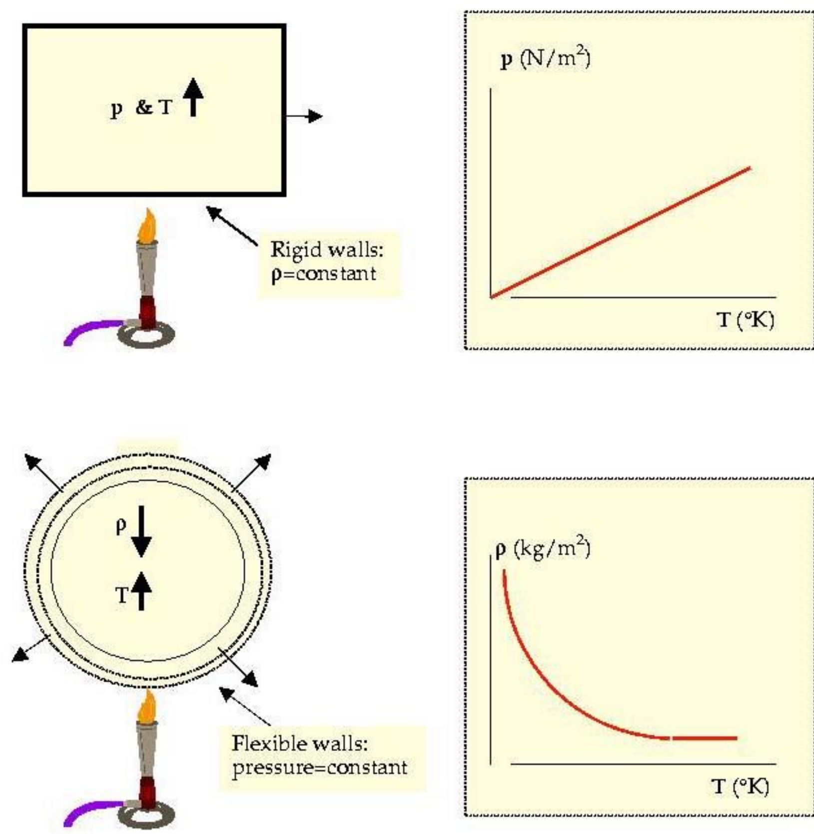
(4) R is a proportionality constant, unique to each gas or combination of gases.

2. The ideal gas law implies that temperature, pressure, and density are not independent. Changing one changes one or both of the others. For example:

> ***a) If we hold density constant, increasing temperature causes the pressure to rise.***

Implications of Ideal Gas Law

$$p = \rho R T$$



3. (Heating a can of soup without opening will cause the can to explode with pressure)

a) If we hold pressure fixed, as temperature rises, density goes down. This means that at the same pressure, warm air is less dense than cold air. This also means that one way of making air less dense is to heat it up. We can create density differences with temperature differences. This is crucial because fluids with different densities resist mixing.

b) In the atmosphere, fronts represent the meeting places between different air masses that have different densities. They push against each other, in part because they resist mixing. We often use terms like "cold front" and "warm front," but the real difference here is density, and air masses will resist mixing even with density differences as small as 1%.

E. Summary:

1. Temperature, pressure, and density are our tools for understanding our atmosphere and it's weather.

2. Pressure exists because the air has weight, and pressure decrease with height.

3. Since air is compressible, pressure decreases exponentially with height, as does density.

4. We recognize that fluids with different densities resist mixing, cold air and warm air at fronts.

5. At sea level, pressure is strong enough to stand a column of water on end 33 feet high, but we saw that it's pressure differences inside and outside of that column, inside and outside of your soda straw, between the surface and the sky that drive Nature into action.

6. Nature wants to move mass from high to low pressure.

7. Our atmosphere is the scene of a great struggle between upward pressure differences and the downward gravity force, representing hydrostatic balance.

F. Questions:

1. Why do cold and warm fronts even exist?

2. Can you dig a well so deep you cannot pump water from it? Explain.

3. How do soda straws really work? Illustrate below

4. How high is the sky?

5. Why do we still have an atmosphere? Explain.

6. Which way do all fluids move?

7. How much of the atmosphere mass resides between the 1000-500 millibar levels?

8. What is the atmospheric pressure at sea level in psi?

9. What is the atmospheric pressure at sea level in pascals?

10. What is the atmospheric pressure at sea level in millibars?

11. What is the atmospheric pressure at sea level in inches of mercury on a barometer?

12. What is the atmospheric pressure at sea level in feet of water on a barometer?

13. What is the significance of the ideal gas law towards the atmosphere?

14. Does atmospheric pressure increase or decrease with increase of elevation?

15. Nothing sucks in Nature! Explain.

16. We have described pressure as largely being the weight of the overlying air. Actually, anything above us should increase the downward force. But, if that's true, why aren't we discomfited, or even crushed, when a large, very heavy airplane flies overhead? (Hint: It has nothing to do with lift).

17. On very hot days, jumbo jets are not permitted to take off or land at some airports, owing to insufficiently long runways, Why?