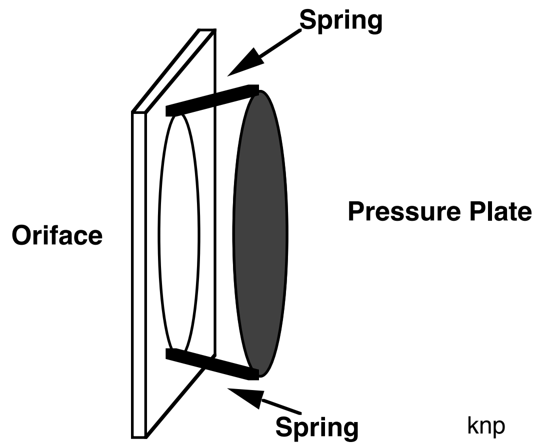
Measurement of Respiratory Volumes[1]

Biology 390 -- Physiology

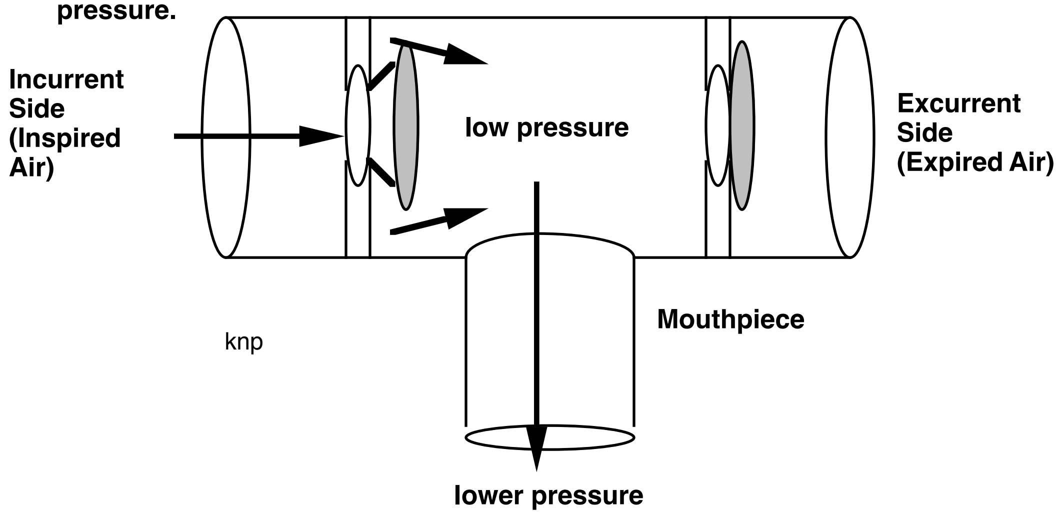
About Valves: The valves we use are designed with two principle goals (i) separate inspiratory from expiratory flows and (ii) use a resistance to flow that is low enough so that breathing is not limited by the valve. They achieve this by incorporating two or more devices (which themselves are the actual valves) that typically work by using a spring mounted plate that is normally held tightly over an orifice. A negative pressure applied on the plate side will cause the valve to open as will a positive pressure on the orifice side:

An opened valve. This position would be achieved by application of negative (below ambient) pressure on the right side or positive (above ambient) pressure on the negative side.



By placing using one or more of these valves on the incurrent (inspiratory) and excurrent (expiratory) sides air can be made to flow in to the subject via one side of the valve assembly and then exit via the other. This is done by orienting the closing plate or the inspiratory valve towards the subject and doing the opposite with the expiratory valve:

Inspiration with a respirometry valve: The sub-ambient pressure created by the subject's inspiratory muscles results in a low pressure in the center of the value. This opens the incurrent valve and at the same time "sucks" closed the excurrent valve! The opposite will happen during expiration. Note how one valve is opened while the other is "pinned" closed, both by pressure.



---

[1] Copyright 2015, KN Prestwich, College of the Holy Cross, Biology Department

? How would you design a breathing valve to minimize resistance to flow?

Measuring Minute Volumes and Breathing Rates:

1. **Impedance Pneumograph**: the impedance pneumograph is a device that utilizes impedance[2] changes that occur in a person's chest during breathing. These changes are more or less linear as the person's chest size changes during breathing. The device applies a very small, constant rms[3]applied voltage is constant, if the impedance changes the electrical energy that is able to be transmitted through the person's chest changes with the impedance. Thus, the changes in electrical current accurately reflect chest volume with respect to time.

Thus, the big advantage of these records is that they are easy to obtain and they accurately reflect instantaneous changes in breathing. They can be fed directly into a computer and analyzed. The one problem with impedance pneumograph measurements is that they are most useful if they are standardized to some known volume. So, typically a calibration curve must be made by having the subject breathe in or out several known volumes both above and below the FRC and then construct a calibration curve. This usually requires the use of a spirometer (see below).

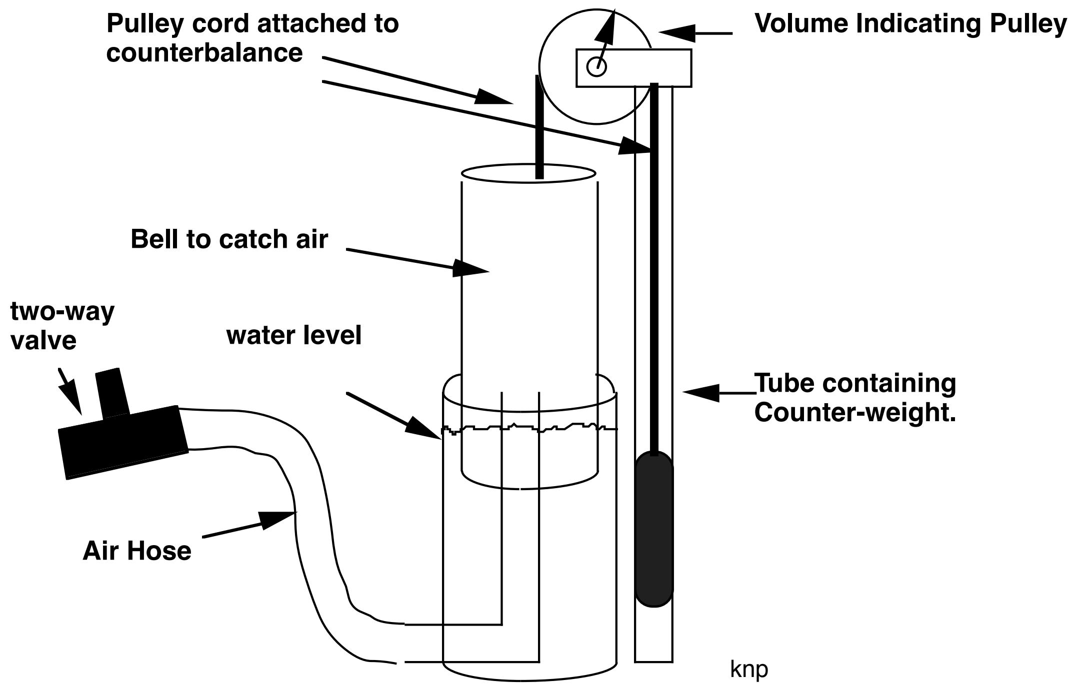
2. **Anemometry**: Anemometers are devices that measure air velocity. You are probably most familiar with meteorological anemometers -- the devices with four cups that spin in the wind and measure its velocity. Anometers can also be built using the principle of temperature change -- these anemometers use devices such as "hot-wires" and thermistors to measure the change in temperature that accompany changes in convection. For instance, in the case of a hot wire, the faster air travels past the wire, the more heat is removed and this is reflected in electrical changes in a circuit that the wire is hooked into. Thermistors tend to rely more on temperature changes that accompany exhaled breath.

3. **Spirometry**: Perhaps the oldest device to measure breathing volumes is the spirometer. The figure below shows the principle of operation -- they capture expired air in such a way that it is measured -- usually either with a pulley device (as in the picture) or sometimes directly by a calibration mark on the capture vessel (bell). Notice that the spirometer by itself only records volumes. To measure flow (volume/time) some means of recording changes in volume with time must be devised. Two means are used -- a rotating drum hooked up to a pen controlled by the spirometer (kymograph) that plots time on the X axis and volume change on the Y.

---

[2] Impedance (Z) is a term that is akin to resistance in that it limits the amount of current that can flow through a circuit at a given voltage. The difference between impedance and resistance is that impedance includes both resistance (often called pure resistance) and terms known as **reactances** that relate to the fact that circuits may have some capacitance and inductance and when present, these appear to consume power like a pure resistance. Reactances only occur in circuits where the voltage is changing such as alternating currents and tend to become more pronounced at higher frequencies. Since the impedance pneumograph uses a very high frequency AC current, therefore, reactances are important.

[3] RMS (root mean square) is a method of measuring average voltage, current or power in an alternating current circuit. The 110 V value that you know of for wall circuits is actually an RMS value. The average voltage for an AC circuit is zero since the circuit has current moving in one direction for half the time and in the opposite (negative) direction the other. RMS voltages are the square root of the average of the squared voltages (or current). Notice that this mathematical trick is identical to what t is done in calculating a statistical standard deviation.

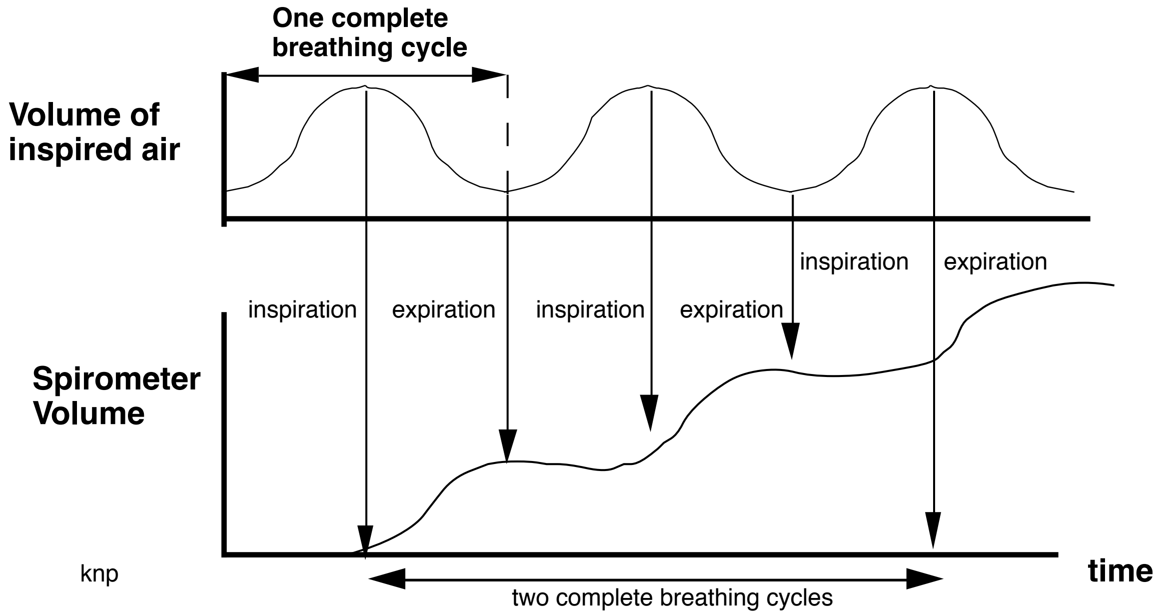


A Bell Spirometer(Vitalometer). When the subject exhales into the hose, air passes through the tube and is captured in a light-weight water-filled bell. The air displaces the water in the bell and it moves upwards. As it does, a counterweight pulls on a pulley cord attached to the bell and causes the pulley to turn in proportion to the amount of air added. Thus, the pulley is a type of analog indicator device. This particular spirometer is termed a "wet"spirometer since it uses water to seal air into the bell; "dry" types use some special type of seal.

Spirometers can also be connected to a computer to obtain volumes and flow rates. Most commonly this is done by connecting the spirometer pulley to an electrical circuit with a variable resistor. As the pulley moves in response to volume changes, the resistance and therefore the circuit voltage changes. An A/D card on the computer can sample this voltage (i.e., read the spirometer volume) at fixed time intervals and the computer can then calculate the flow rate as the slope of the line between any two volume-time points.

(please go to the next page)

<u>How to use the spirometer</u>:



Breathing and Spirometer recordings:
Top panel: Volume of air inspired and expired.
Bottom Panel: Spirometer record of the breaths above. If the spirometer is configured to capture expired breath (as in the previous figure) the volume will only begin to increase at the start of expiration (at what is called respiratory mid-point) and will stop increasing once the expiration is complete. Due to the use of a valve, when the subject inspires there is no change in spirometer volume (the inspired air comes from the room, not the spirometer).
Important Note: In order to gain an accurate measurement of the breathing rate (f, breaths/min) and expired minute volume (V_E, the volume of air expired per minute) complete breathing cycles must be used. This would normally be accomplished by measuring both volume and time starting with the first movement of the spirometer and then stopping the measurement at the first movement after the last breath that was to be counted.

? Suppose that it takes six seconds to complete two cycles and the spirometer volume increases by 1 liter. Calculate V_E (liters/min) and f (breaths/min). Be sure you can do this by the start of class.