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in the classroom

## ARDMS Topic:
## Doppler Imaging Concepts

# Unit 18: Hemodynamics

Sononerds Ultrasound Physics
Workbook & Lectures

# Unit 18: Hemodynamics

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# Unit 18: Hemodynamics

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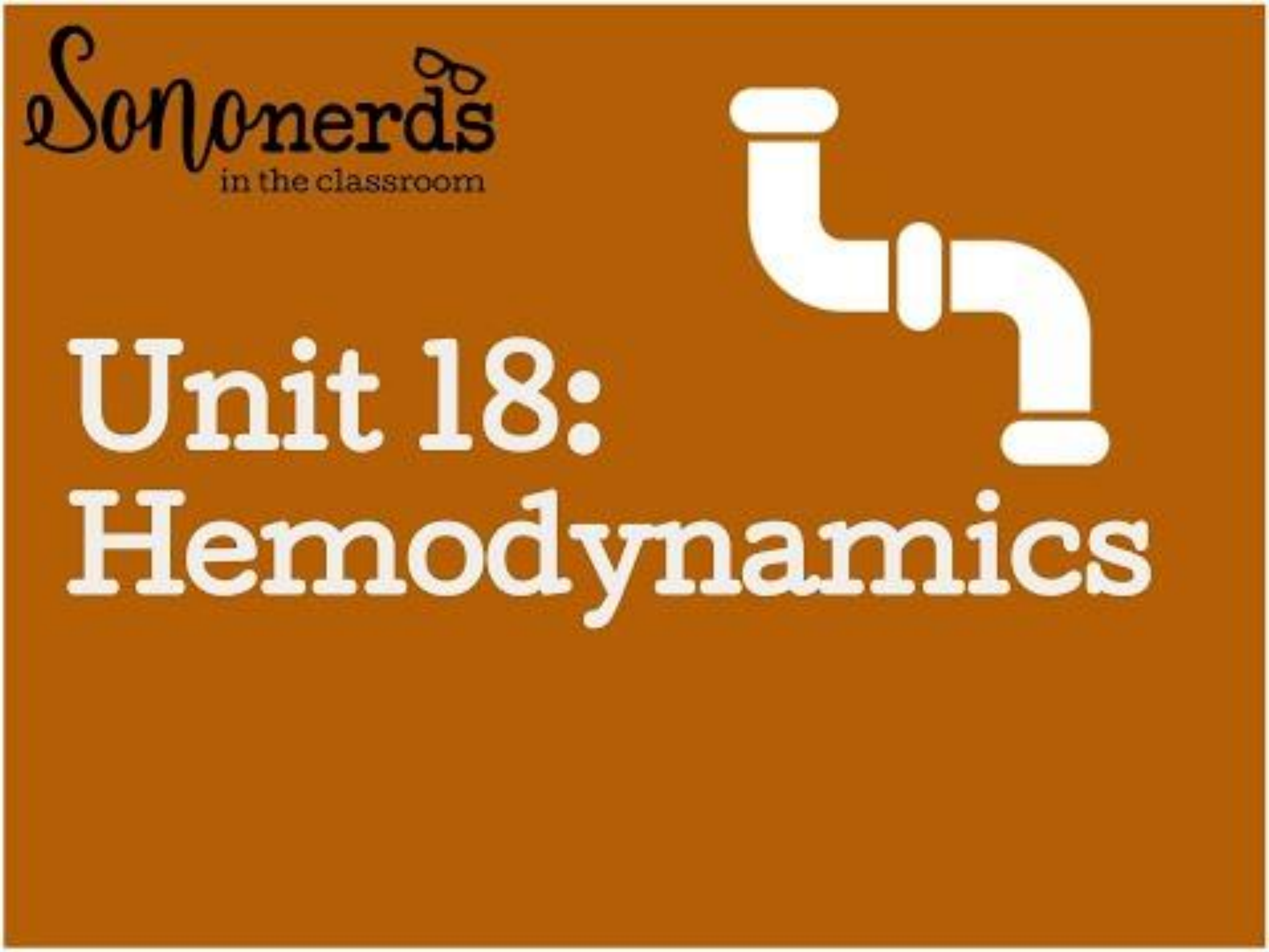


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# Unit 18: Hemodynamics

- **Hemodynamics is the study of blood as it moves through the circulatory system**

There are two important ideas that we want to keep in mind as we learn about hemodynamics and Doppler:

Volume Flow Rate

Also known as Flow Rate or just Flow, we are interested in knowing how much blood is moving through any given point of the circulatory system. This is typically expressed in a volume/ time, like gallons/second or mL/second.

Velocity

We also want to know how fast blood is flowing through any given point in the circulatory system. Velocity recognizes a speed and a direction. The speed part of it is expressed in a distance/time, like cm/second. The direction, in ultrasound is usually away from the transducer or towards.

Speed → 50 miles per hour (mph)

Velocity → 50 mph heading east

# Section 18.1 Flow of Fluid

Studying hemodynamics takes a lot of cues from fluid dynamics, because the vessels in the body are basically just a big system of pipes with a slightly thicker fluid (blood) flowing through them. The heart acts as the pump and propels the fluid through the body. The blood is susceptible to extrinsic physical forces such as pressure, resistance and size of the tube. This changes how the blood flows

So we need to know how these physical properties affect blood flowing through the body and how the body can affect the flow, both in how much is flowing and how it is flowing.

## 18.1.1 Fluid Dynamics

There are a few key terms that you should be familiar with as we talk about the how fluid flows.

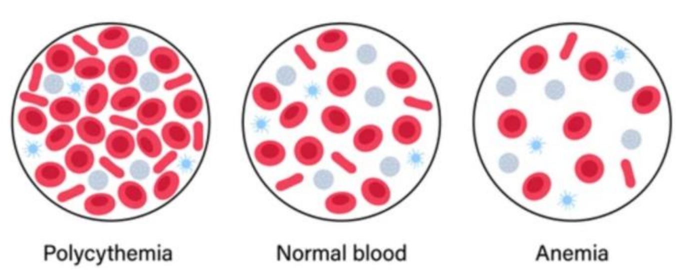
- **Viscosity - the resistance of a fluid to flow**

Viscosity describes the thickness of fluid. Think about pouring water out of a pitcher and pouring honey out of pitcher. Which would allow for *faster* flow? Which would allow more to flow over one minute? The water, which has low viscosity flows easily, the honey, which has a high viscosity would flow very slowly.

The unit for viscosity is the **poise.**

Average blood is about 5x thicker than water. However, there are medical conditions that can change the thickness of blood, by changing the amount of red blood cells.

- **Anemia** (few RBCs) causes the blood to thinner or less viscous
- **Polycythemia** (too many RBCs) causes the blood to be thicker or more viscous
- **Hematocrit** is a blood test that can tell what percentage of blood is made up of RBCs.

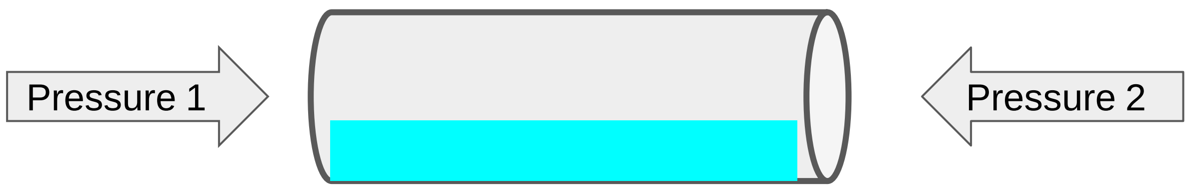


→ **Pressure - driving force behind fluid flow**

For fluid to flow, there **must be a pressure difference.** Pressure is measured in units of **force per unit area.** For example, the air pressure in our tires is pounds per square inch (PSI) and we already learned about Pascals.

When looking at pressure that affects the circulatory system, there are two main sources. **A pump (the heart) and gravity.**

Imagine a pipe with fluid in it:



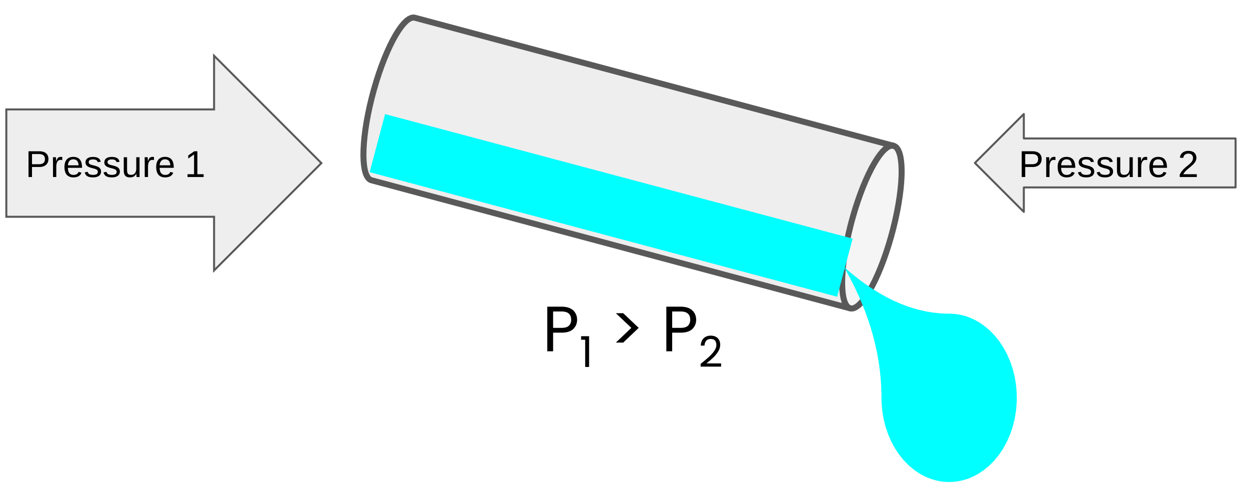

$$P_1 = P_2$$

→ **If the pressure is equal on both sides, there is no flow.**

Now imagine if we increase the pressure on one side, by raising it or pushing on it like a pump would. We have now made a **pressure gradient.**

→ **Fluid flows from high pressure to low pressure**
→ **Fluid flows from high resistance to low resistance**

It would take a lot of opposite force to keep fluid from flowing and if it doesn't exist, the fluid will start to move.




$$P_1 > P_2$$

- **Volumetric Flow Rate**

We did already touch on this, but we're working towards one of our first formulas related to flow, so let's cover it again. Volumetric flow rate, sometimes just referred to as flow, is the amount of blood that passes a point in the system over a certain amount of time. For example, when we think about faucets, we consider an output of one gallon per minute to be adequate.

Volumetric flow rate uses units of **mL/minute or mL/second.** The adult cardiac output is typically about 5000 mL/minute and with 5 liters of blood in the body (5000 mL) it take about 1 minute for all of your blood to circulate and return.

Here is our first formula for flow rate. This is assuming a long straight tube. Note that this symbol Δ is the greek letter delta and means "change."

$$Q = \frac{\Delta P}{R}$$

Q = Flow rate, measured in mL/s

P = Pressure, measured in dyne/cm$^2$ (force/area)

R = Resistance, measure in poise

Knowing our formula relationships, we can confidently say that when the change in pressure increases, the flow rate will increase, because they are directly related. Example: if we raise one end of a tube a little , there is flow, but if we raise it a lot, there is more flow.

If resistance increases, flow rate with decrease as they are inversely related. This relates back to our water vs. honey.

We know that viscosity is a factor to the resistance of flow, but there are actually other factors that go into the "R" of the previous equation. Those include the length of the tube, and the radius of the tube.

To calculate R, we would use this formula:

$$R = 8 \times L \times \frac{\eta}{\pi \times r^4}$$

L = Length, measured in cm

η = viscosity, measured in poise

r = radius, measured in cm

- ➔ **The only thing you need to know about this equation, is that when a factor causes resistance to increase, flow rate will decrease.**

Flow rate decreases when viscosity increases (causes R to increase).

Flow rate decreases when length increases (causes R to increase).

Flow rate decreases when radius decreases (causes R to increase).

### 18.1.2 Poiseuille Equation

If we combine the volumetric flow rate and the resistance equation, we can then derive Poiseuille's Equation.

By using Poiseuille's equation we can make assumptions about how blood will behave in the body.

There are two formats that Poiseuille's can take, one using radius and one using diameter:

$$Q = \frac{\Delta P \times \pi \times r^4}{8 \times L \times \eta} \qquad Q = \frac{\Delta P \times \pi \times d^4}{128 \times L \times \eta}$$

As with the other formulas, here are the big takeaways:

- ➔ **If length increase, flow rate decreases**
- ➔ **If viscosity increases, flow rate decreases**
- ➔ **If the pressure change increases, flow rate increases**
- ➔ **If the diameter or radius increases, flow rate increases**

Now the last takeaway is important. Arterioles are VERY tiny arteries -the last before connecting to capillaries and transitioning to veins.  The arterioles have muscular walls that can relax and contract, thus changing the diameter (radius) of the vessel.

This is on purpose and it is so the body can control how much blood goes to specific organs.  By changing the diameter, the body can increase or decrease the flow of blood to an organ.

Another thing that Poiseuille's equation assumes is *laminar flow.*

# Section 18.2 Types of Flow

There are 2 distinct ways in which we look at blood flow:

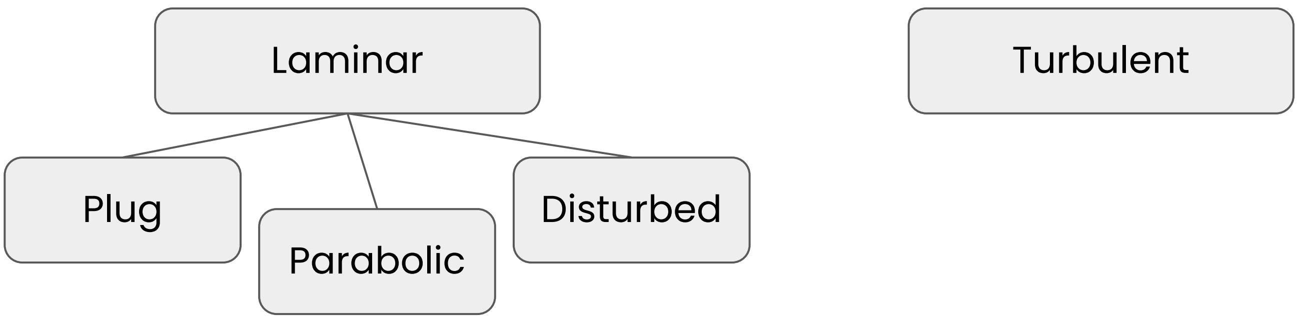
1. How do the streamlines of blood flow within the vessel?
2. How does the heart or respiration affect blood flow?

The 1st is still related back to the basic principles of fluid dynamics, but applies to blood flow. The second is directly related to body in relationship to bodily functions and vessel location.

# 18.2.1 Laminar & Turbulent Flow

There are two types of fluid flow that we need to know:

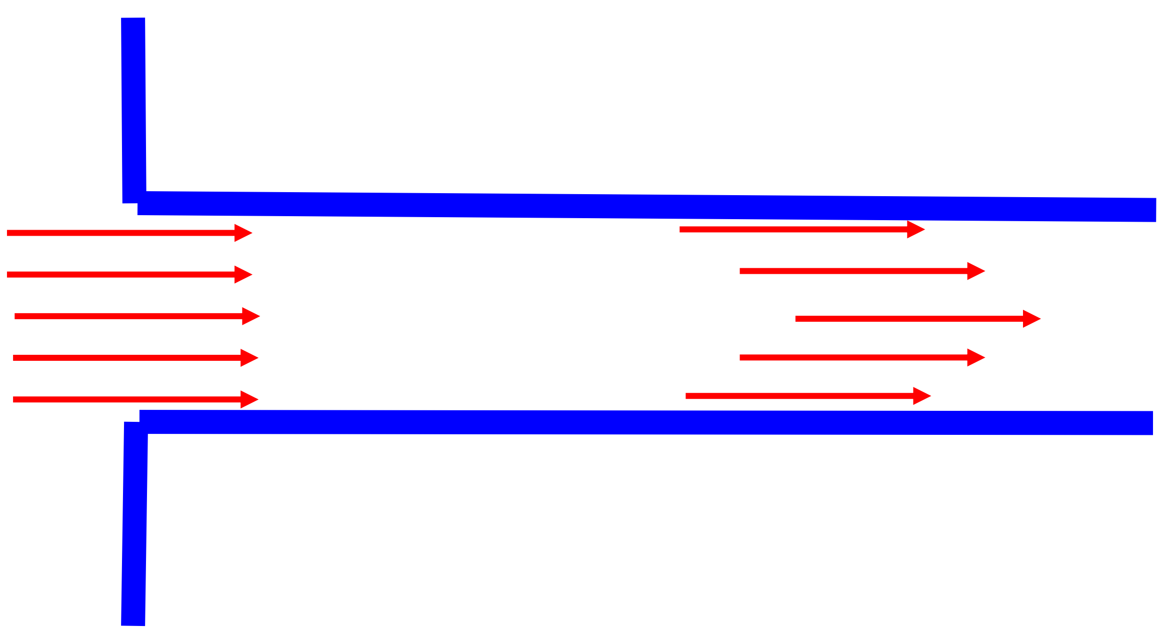

Laminar flow can be further divided into:



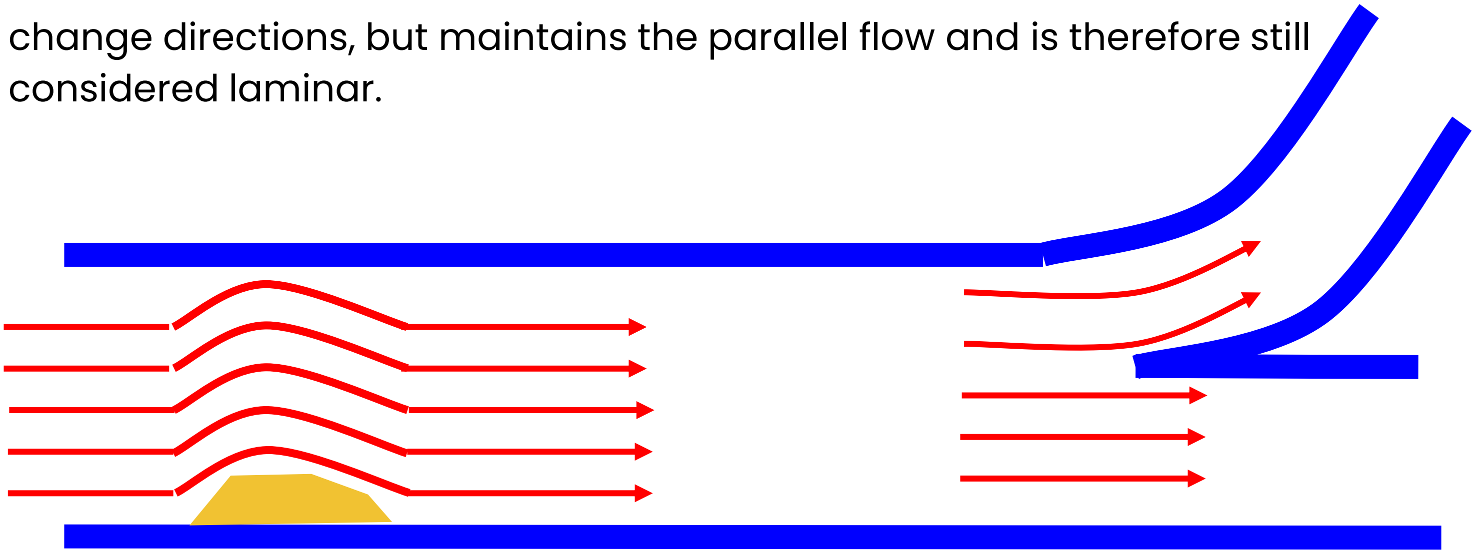

When fluid flows, it has **streamlines.** Streamlines are "layers" of fluid that flow through an area. By observing these streamlines, we can categorize the type of flow.

If we see all layers traveling **parallel, straight, & at the same speed,** we would say this is **laminar plug flow**. Laminar plug flow is often seen at the beginning of vessels.

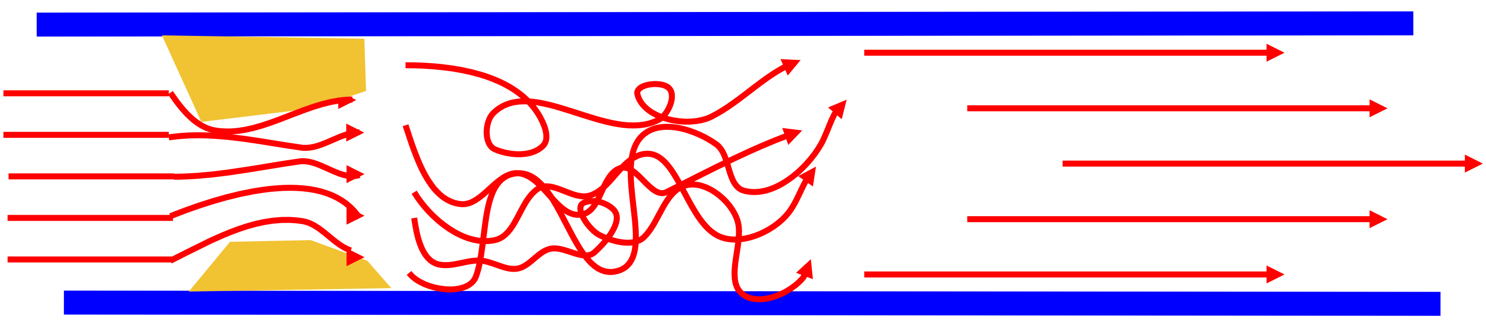
As the fluid travels into the vessel, the outer layers are going to slow down due to friction, the next innermost layers are going to slow down due to friction with the outer layers, ultimately making the center streamline the fastest moving part of the blood (least amount of resistance). **Parallel, straight & varying speed** streamlines is classified as **laminar parabolic flow.**



As blood flow through a vessel, it may encounter a branch or a slight narrowing. This can cause **parallel & not-straight** streamlines, or **disturbed flow.** Disturbed flow cause the blood flow to move around an obstruction or change directions, but maintains the parallel flow and is therefore still considered laminar.



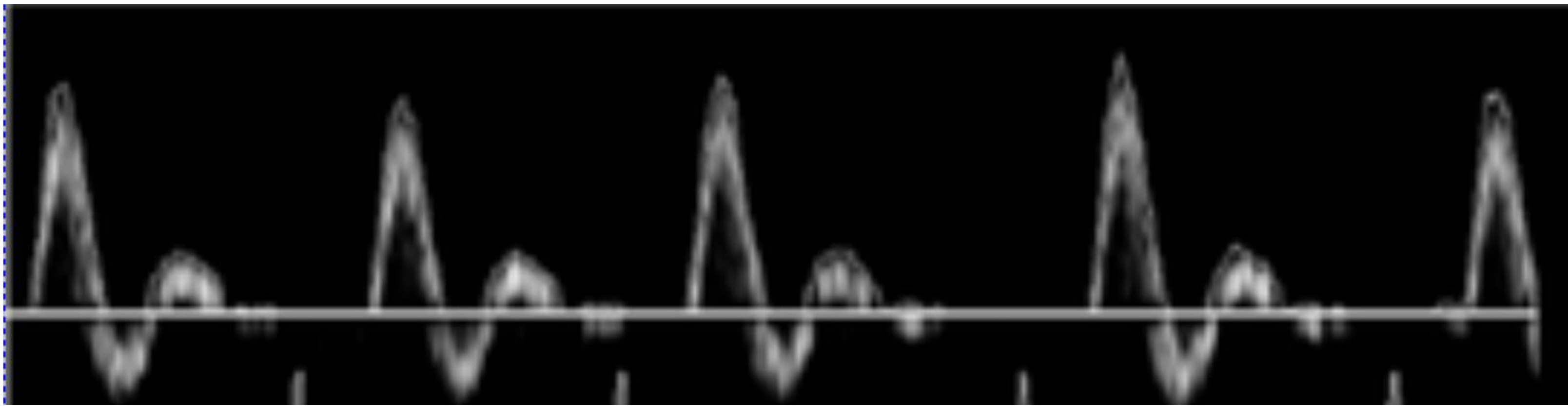
When the streamlines become **chaotic, turbulent flow** is seen. The streamlines are not well noted, there is swirling of the blood referred to as **eddies & vortices.** Forward flow is mostly maintained during turbulent flow. Turbulent flow is most commonly seen when flow is fast, especially following a severe stenosis in the vessel, where blood moves from a small fast area to a wide slow area.



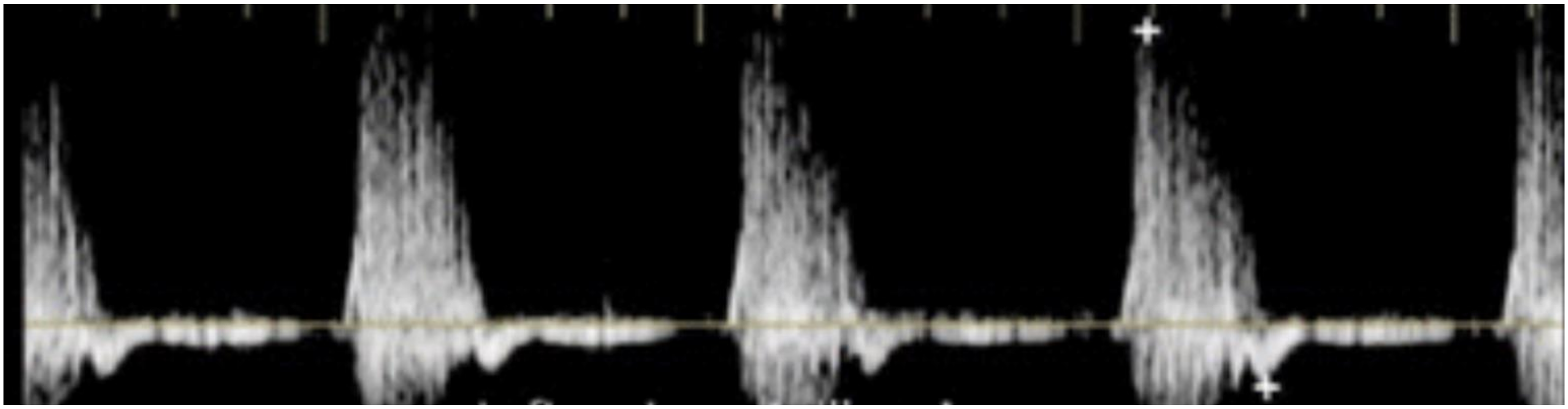
Another interesting thing between turbulent flow and laminar flow is that laminar flow is **silent.** However, turbulent flow is audible and palpable. When a physician listens to the blood flow, the turbulent flow can be heard and is called **bruit.** In areas that turbulent flow can be felt, it is called a **thrill.**

In the next unit, we'll learn about spectral tracings, the results of performing PW Doppler. The white line represents individual blood cells that the machine is detecting reflection off of.

When laminar flow is observed with spectral tracing, it shows a thin line as most of the RBCs are traveling at (or near) the same speed. Laminar flow is normal physiological state of blood.



Where turbulent flow is observed with spectral tracing shows a line that is filled in as there are blood cells travels at all different speed in different directions. Turbulent flow often follow an area concern like a critical stenosis.



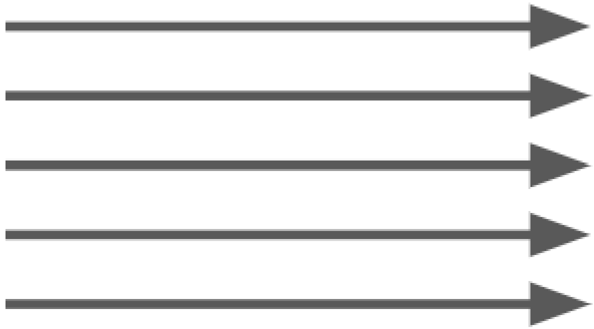
## 18.2.2 Reynold's Number

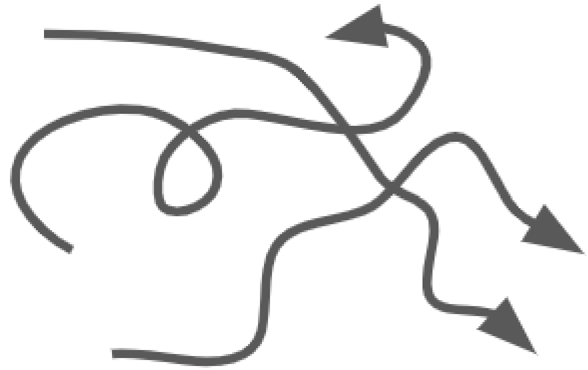
Reynold's number is a unitless number that can predict the type of flow that will be present.  It considers the velocity, density and viscosity of the blood moving  through the radius of a tube. The formula & calculation aren't necessary to know, but you should know what the numbers mean:

| <1500 | 1500-2000 | >2000 |
|---|---|---|
| Laminar Flow | Indeterminant | Turbulent Flow |

LAMINAR vs.

TU





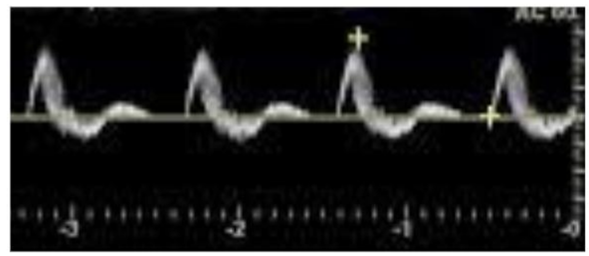
Silent Loud

<1500 >2000

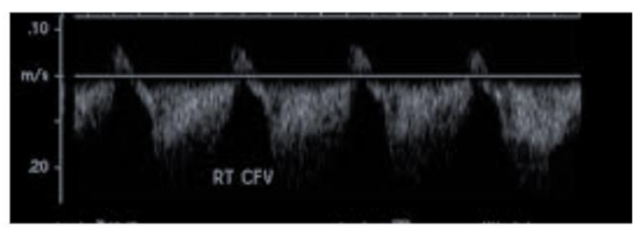
# 18.2.3 Blood Flow in Vessels

There are three common types of flow in the vessels that we commonly see:

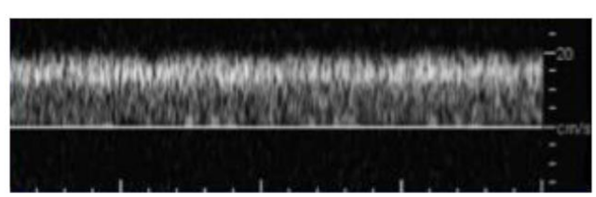
- **Pulsatile Flow**
  - Blood moves at variable velocities
  - Caused by cardiac contractions
  - Typically seen in arteries
  - High flow rate
  - High pressure



- **Phasic Flow**
  - Blood moves at variable velocities
  - Caused by respiration
  - Typically seen in veins
  - Low flow rate
  - Low Pressure




- **Steady Flow**
  - Blood moves at a constant speed
  - Typically seen in veins while holding breath



# Section 18.3 Energy

When the heart is relaxed, blood fills the left ventricle and the muscles are static, holding potential energy. When the left ventricle contracts, it forces blood out transferring that potential energy into pressure energy and kinetic energy.

As the blood moves through the body, some of the energy is lost as it is converted into other types of energy.

## 18.3.1 Energy Loss

- **The Law of Conservation tells us that:**

**Energy cannot be created or destroyed, but it can be transformed.**

The three most common ways the circulatory system loses energy due to transformation are:

1. **Viscous loss**
2. **Frictional loss**
3. **Inertial loss**

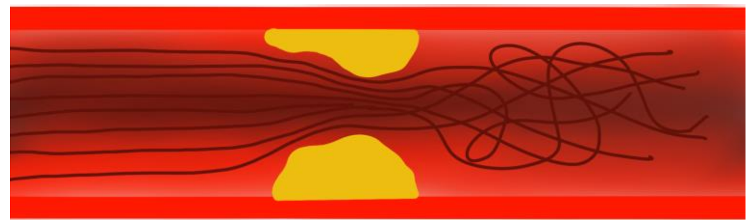
Viscous loss occurs due to the blood being thicker. It must overcome its own "stickiness" to move.

Frictional energy loss occurs as blood cells move through a vessel. Some of the cells will drag on the vessel wall causing friction. The friction is transferred in to **heat.**

Inertial energy loss occurs when blood changes directions. This is commonly seen with pulsatile flow, phasic flow and stenotic areas.

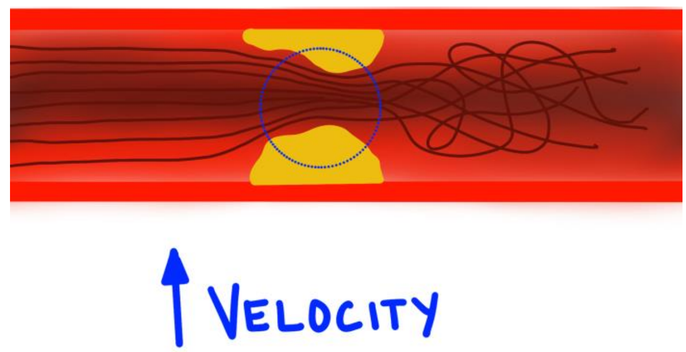
# 18.3.2 Stenosis

A stenosis is a narrowing of the lumen of a vessel. A stenosis causes a significant change in the way blood flows.

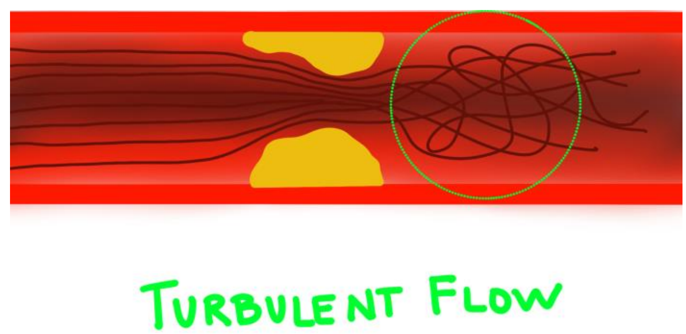


There are 5 changes that happen when blood flows through a stenosis:

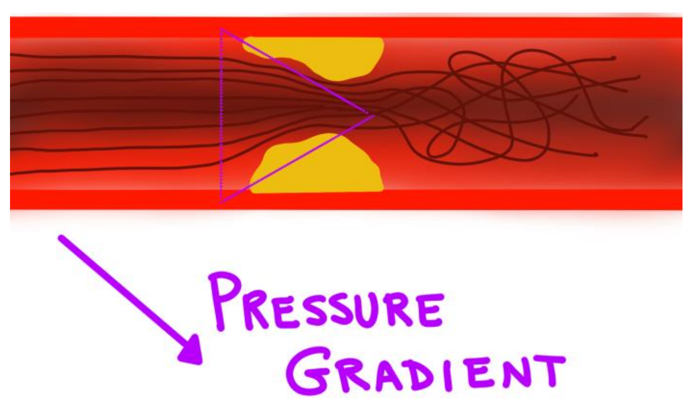
1. The blood flow changes directions as it flows into a narrowing and out.



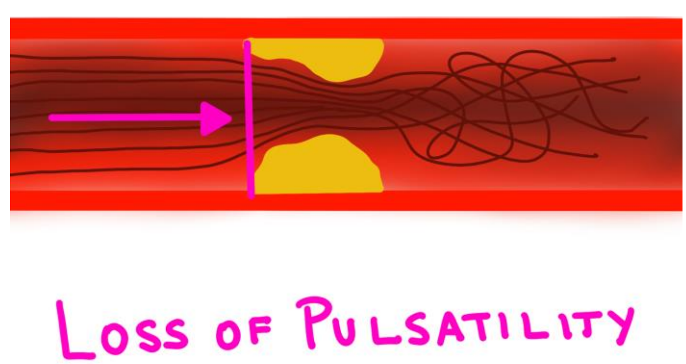

1. Velocities increase through a narrowing




1. Turbulent blood flow is seen distal to a narrowing




1. There is a pressure gradient within the stenosis




1. Loss of pulsatility

# 18.3.3 Bernoulli's Principle

Poiseuille's law told us that in a long straight tube, when the diameter reduces the flow rate will also decrease. This is true when the WHOLE tube's diameter changes.

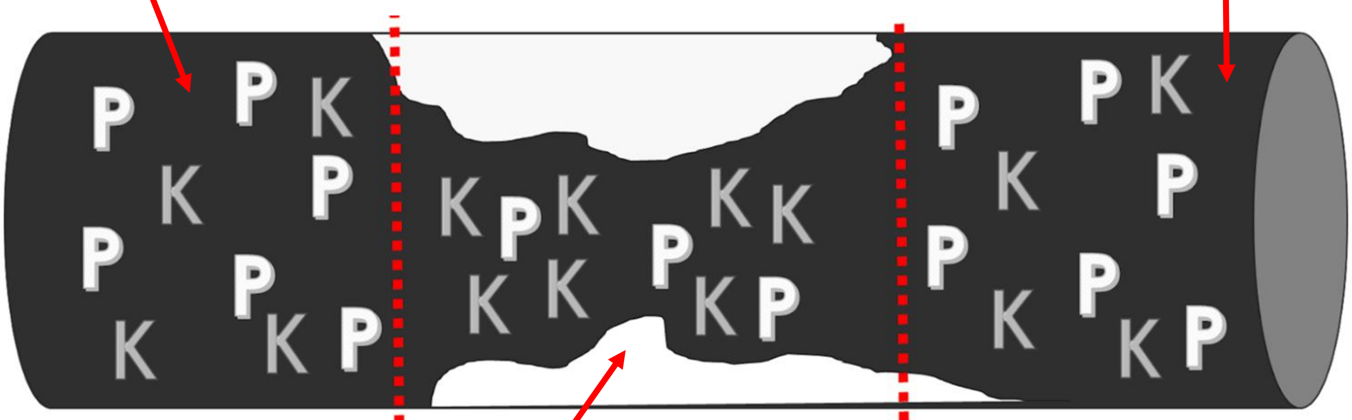
BUT when we have an abrupt narrowing in the tube, like a stenosis, Bernoulli's Principle is in action.  Bernoulli's principle tell us that in a stenosis:

- ➔ **Pressure is lowest in the the stenosis**
- ➔ **Velocity is highest in the stenosis**

**Bernoulli's makes sure that the law of conservation is followed.**

Pressure energy is higher & kinetic energy is lower before the stenosis

After the stenosis, the pressure increases again as the kinetic energy reduces, thus conserving the energy.



To maintain energy in the stenosis, some pressure energy converts to kinetic energy. Increased kinetic energy means increased velocities.  This occurs because the body still needs to get the blood back to the heart, it can't slow down everytime it reaches a narrowing.

# Section 18.4 Hydrostatic Pressure

- **Hydrostatic pressure describes the relationship between the weight of blood, gravity and height.**

$$P = h \times g \times \rho$$

P = hydrostatic pressure

g = gravity

h = height of fluid

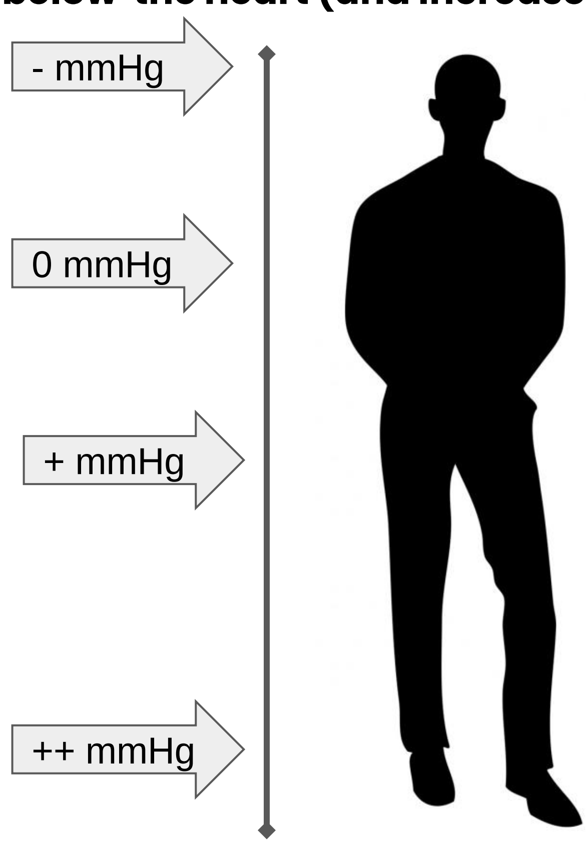
ρ (rho) = density of fluid

**When any of the variables increase, the hydrostatic pressure will also increase because they are directly related.**

Hydrostatic pressure is created when a column of fluid such as blood is acted upon by gravity. The density of the fluid and the distance from a particular point also matter. In the case of the body, we use the heart as point 0.

If we think of the heart as 0 on a number line, then in the standing patient :

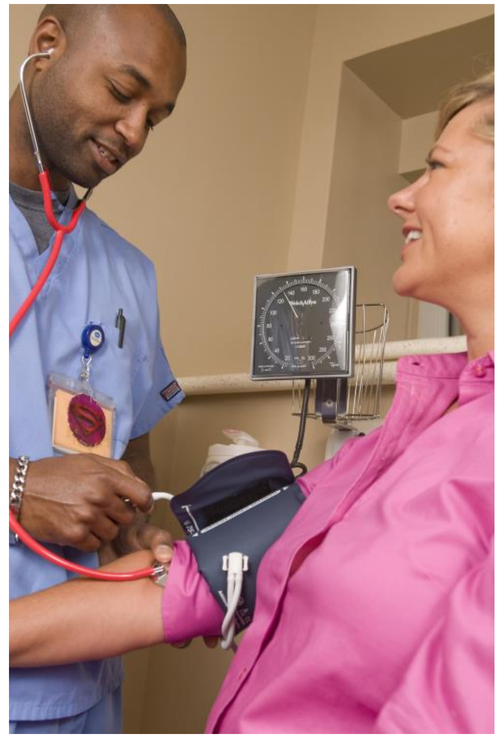
- **Hydrostatic pressure is negative above the heart**
- **Hydrostatic pressure is positive below the heart (and increases the further from the heart you get)**




**Hydrostatic pressure is reported in mmHg (millimeters of mercury)**

You've most likely been to the doctor and had your blood pressure taken. Have you ever wondered why they take it at your arm? The measured pressure that we see as our blood pressure is affected by hydrostatic pressure, so we take the reading as close to the heart as possible.

- **Blood pressure + hydrostatic pressure gives us the total measured pressure.**



$$BP\ (mmHg) + HP\ (mmHg) = MP\ (mmHg)$$

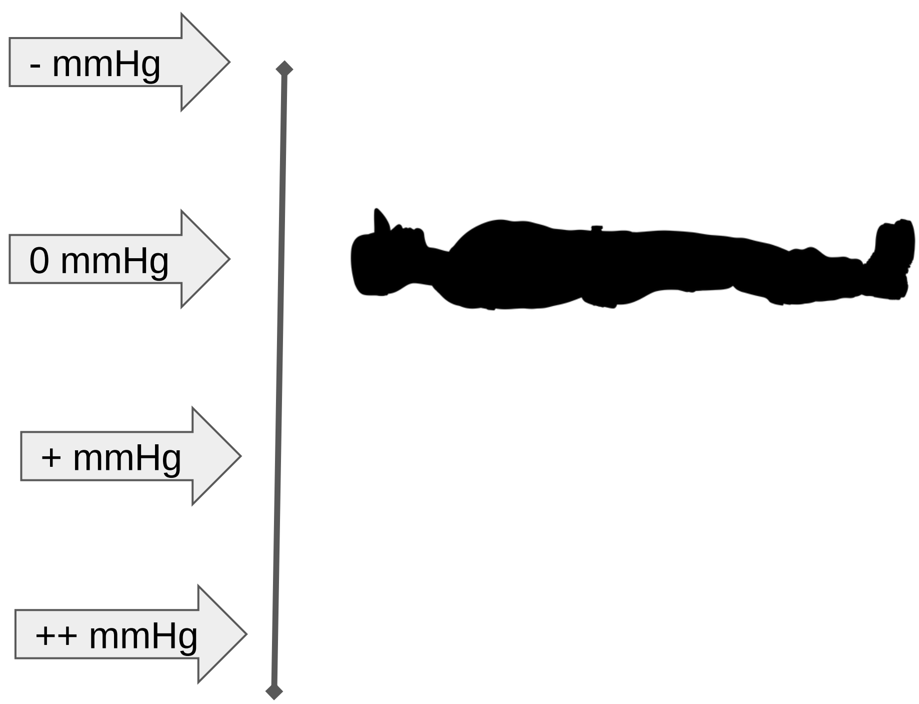
MP = measured pressure, this is the reading on a blood pressure cuff .

BP = blood pressure, value without any effect of hydrostatic pressure

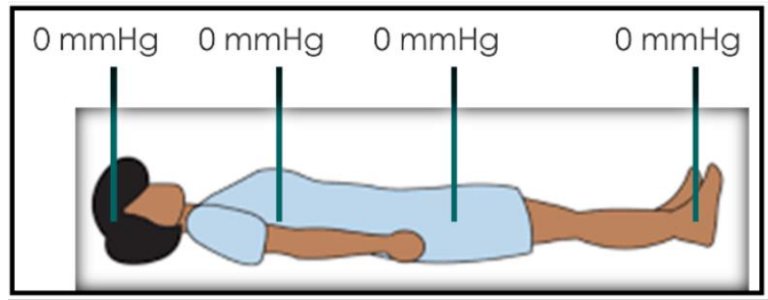
HP = Hydrostatic pressure

The more hydrostatic pressure there is, the higher the measured pressure will be. So if we are at the level of the heart, using a cuff, then in theory, we should be adding 0 mmHg of Hydrostatic pressure and we are accurately measuring true blood pressure.

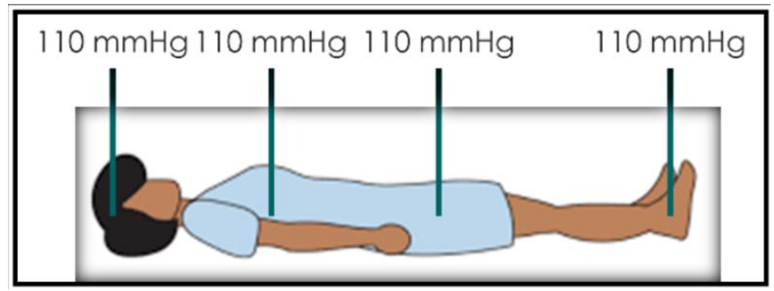
But what do think happens when the patient is lying down and the whole body is at the level of the heart?



Let's say we have a patient with a blood pressure of 110 mmHg. When this patient is laying down (supine) their body is all at the same level of the heart.  This makes the hydrostatic pressure 0 mmHg throughout the body.



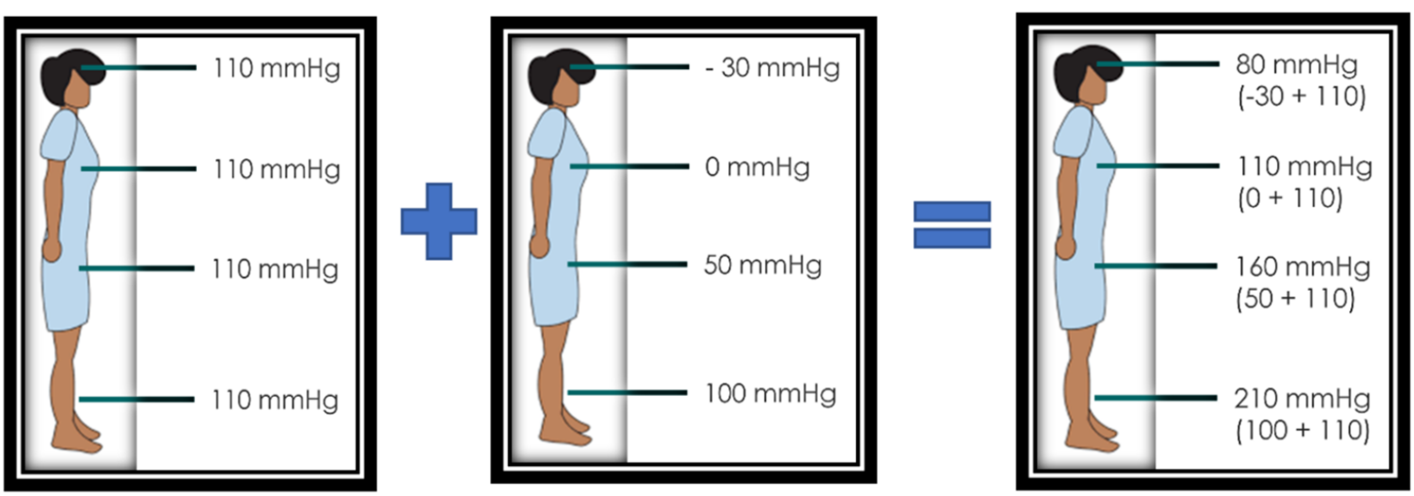

Knowing that measure pressure is the sum of hydrostatic pressure + blood pressure, we can calculate the measure pressure at 110 mmHg at every point in the body.




There is no hydrostatic pressure in this scenario, therefore the measured pressure is a true reflection of the patient's blood pressure.

Now let's take the same person with  a BP of 110 mmHg and stand them up. We have now created a column of blood, which will create hydrostatic pressure. Remember that the heart is considered our "baseline" or zero.

Depending on where we measure in the body, we will add hydrostatic pressure.

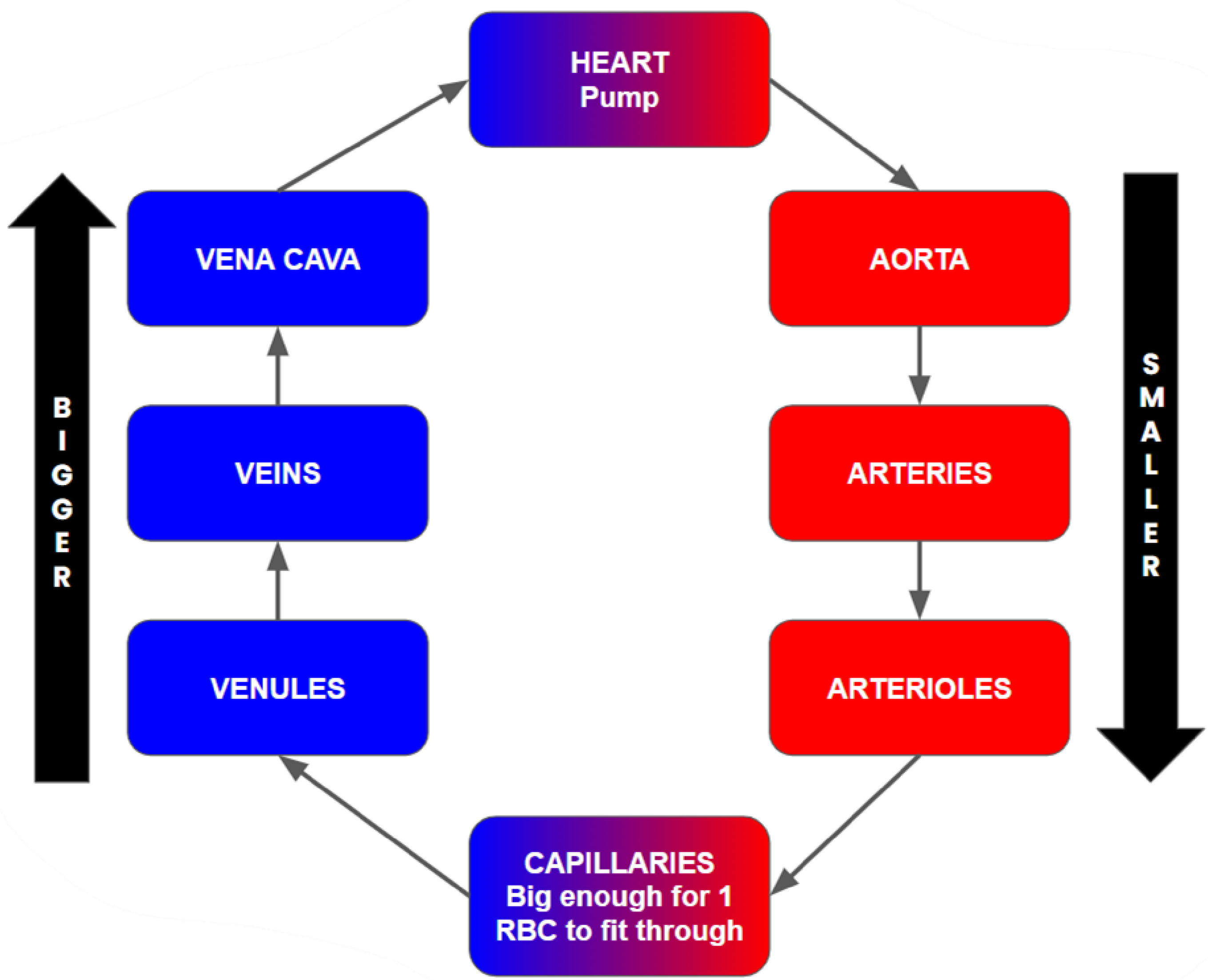



BLOOD PRESSURE + HYDROSTATIC PRESSURE = MEASURED PRESSURE

Note that the numbers given in this scenario are representative, everyone's added hydrostatic pressure is slightly different.  You should understand the concept that  above the heart is negative hydrostatic pressure and that below the heart is positive hydrostatic pressure, with increasing values the further we move from the heart.

# Section 18.5 Vessel Considerations

The circulatory system starts at the heart, the left ventricle creates pressure, propelling blood into the aorta, the aorta becomes arteries, then arterioles and then capillaries. The capillaries are the tiniest vessel, allowing for nutrients and waste exchanges to occur. To return to the heart, the capillaries become venules, then veins, leading to the vena cava where it returns to the heart.



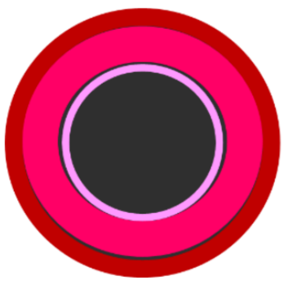
# 18.5.1 Vessel Anatomy

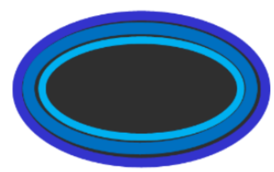
Both veins and arteries are made up of the same layers:

- Tunica intima, the innermost layer made of epithelial cells
- Tunica media is the middle layer made up of muscle and elastic tissue
- Tunica adventitia, the outermost layer made up of connective tissue.
    - This layer has its own blood supply called the vaso vasorum.

The size of the muscular layer is greatly different in arteries and veins. The arteries must be able to handle increased pressure as it is the first to receive blood from the heart. The pressure changes from the heart pumping can be felt on arteries as our pulse.

Veins have valves in them that keep blood from flowing backwards.

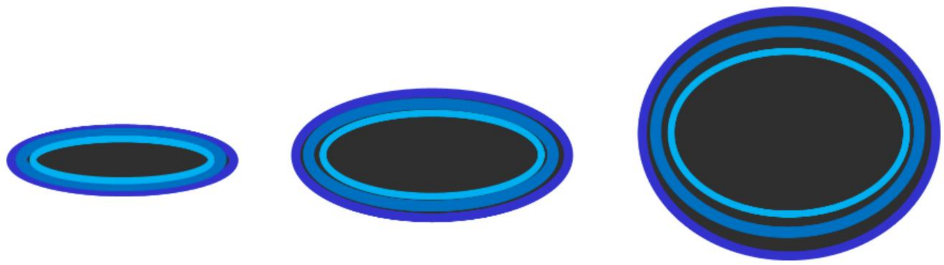




# 18.5.2 Vessel Effect on Blood Flow

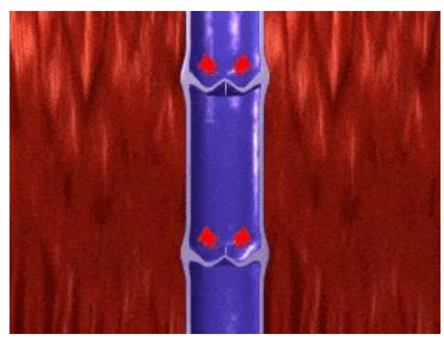
Arterioles are responsible for both vasoconstriction and vasodilation. This is where downstream pressure changes occur. In vasoconstriction, the arterioles increase pressure, causing the flow of blood to lessen. Opposite to that is vasodilation where the muscular wall relaxes allowing for increased flow. This physiological occurrence is directly related to the flow rate and Poiseuille's equations we learned. The diameter of the vessel changes, thus changing our flow rate.

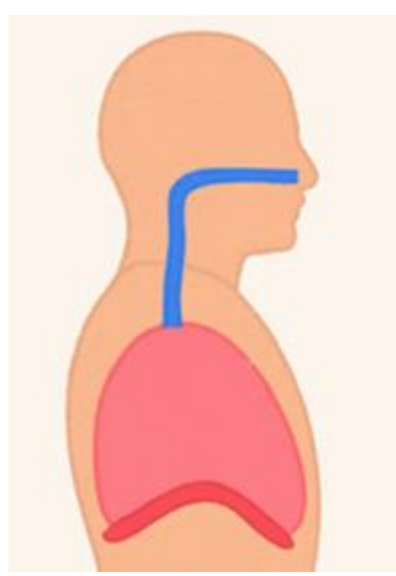
The venous system holds about two thirds of the total volume of blood in the body. The venous system has high capacitance, or the ability to hold a volume. The venous walls are very flexible. In a low pressure setting, the walls will collapse, but they are flexible and allow for expansion when pressure is high. When the body needs to return a large volume of blood to the heart, such as during exercise, the veins expand, thus lowering resistance and increasing diameter. These changes allow for the volume flow rate of the blood to increase as we learned in Poiseuille's equation.



## 18.5.2 Respiration & Venous Flow

Blood gets back to the heart through the veins. We know there must be a pressure difference to accomplish this and there is, albeit very tiny.  The venous system has about 15 mmHg where the right atrium has about 8.  This pressure difference and some other key mechanisms help return blood to the heart:





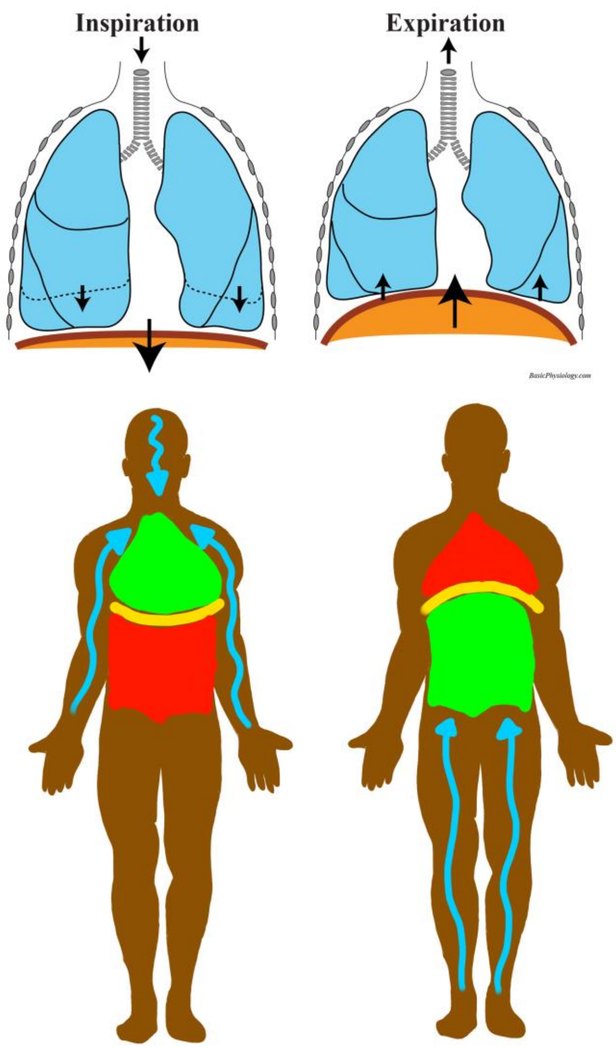
- Veins contain valves. These valves close periodically to keep blood flowing the correct direction.
- The calf-muscle pump. As the calf muscles squeeze, the soleal sinuses (small vein cups that hold blood) are forcefully emptied of their blood, which propels the blood towards the heart.
- Changes in respiration change pressure in the thoracic and abdominal cavities, changing the amount of blood that flows in from veins.

**Inspiration**

When we inhale pressure in the thoracic cavity decreases and pressure in the abdomen cavity increases. This decrease in pressure in the thoracic cavity allows for blood return from the arm and head more easily.  The return from the abdomen and legs cannot overcome the change in pressure and stops or decreases during inspiration.

**Expiration**

During expiration then, the diaphragm moves up into the thoracic cavity. This creates more pressure in the thoracic cavity and decreases the pressure in the abdomen. This now allows for abdominal and leg venous flow to move towards the heart again. It in turn, stops or decreases the blood flow coming from the head and arms.

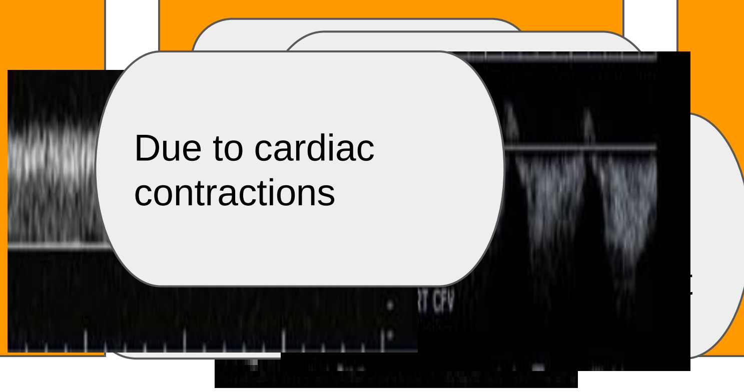



| Inspiration | | Expiration | |
|---|---|---|---|
| **Increases** | **Decreases** | **Increases** | **Decreases** |
| Abdominal Pressure | Thoracic Pressure | Thoracic Pressure | Abdominal Pressure |
| Upper Venous Flow | Lower Venous Flow | Lower Venous Flow | Upper Venous Flow |

# Section 18.6 Activities ← Link to Answers

1. Sort the characteristics for the types of flow in the body

| Pulsatile | Phasic | Steady |
| --- | --- | --- |
| | | |



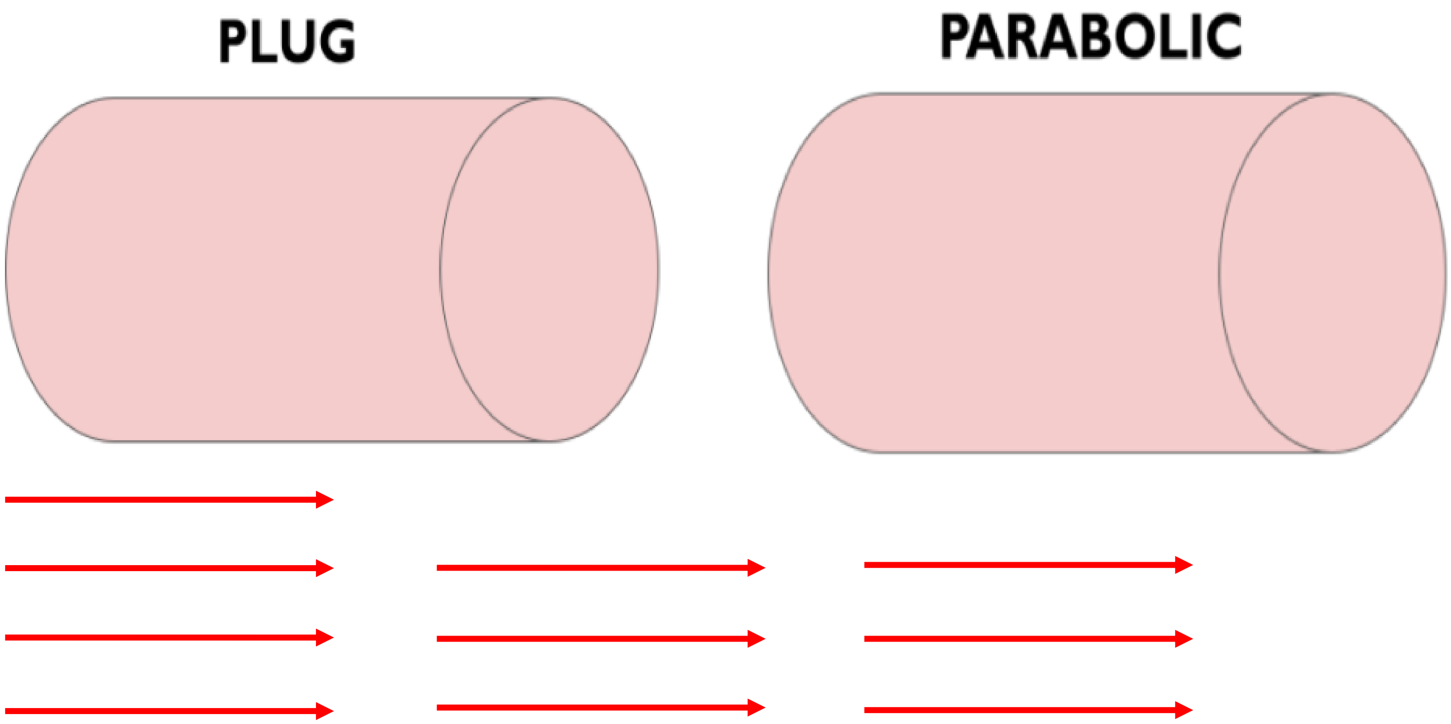
Due to cardiac contractions

2. Write an: **L** if the statement refers to laminar flow

**T** if the statement refers to turbulent flow

| | |
|---|---|
| | Predicted by a Reynolds number > 2000 |
| | Flowlines become chaotic |
| | Flowlines are parallel |
| | Flow is palpable as a thrill |
| | Flow is silent |
| | Flow is normal |
| | Predicted by a Reynold number < 1500 |
| | Flow is found after pathology |

3. Place the streamlines so they represent each type of flow




4. What are the 3 types of energy loss?

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |

5. Fill in the blanks:

| | |
|---|---|
| Viscosity is measured in the unit _______. | |
| Honey is a _______ viscous substance. | |
| Water is a _______ viscous substance. | |
| ______ is a lab test that measures the amount of RBCs in blood. | |
| When blood cells drag along blood cell walls, it causes _______. | |
| Frictional energy is transformed into _______. | |
| Inertial energy loss happens with 3 events in the body. Pulsatile flow, phasic flow and at a _______. | |

6. What are the 5 things that happen at a stenosis?

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

7. Describe Bernoulli's Principle

8. Look at Poiseuille's Law. What will cause an **increase** in the flow rate?

$\Delta P$ $d^4$ $L$ $\eta$

$$Q = \frac{\Delta P \times \pi \times d^4}{128 \times L \times \eta}$$

A decrease in these variables causes an increase in flow rate.

An increase in these variables causes an increase in flow rate.

9. Fill in the blanks:

The venous system has high _______________, meaning it can hold a lot of blood circulating in the body. The venous system has very thin, flexible walls allowing the veins to _______________ when needed, like during exercise. This physiological change in shape is ____________________ equation in action.

In a low need state or low internal pressure the vein walls ________________. This causes the diameter of the vessel to be small, which reduces diameter and increases resistance. When more blood needs to return to the heart, the veins expand. This increases the __________________ and lowers _________________.

# Move the blocks to make the statements true.

Hydrostatic pressure is above the heart.

Hydrostatic pressure is below the heart.

POSITIVE

NEGATIVE

11. Fill in the chart for the **supine patient:**

| SUPINE PATIENT | Blood Pressure | Hydrostatic Pressure | Measured Pressure |
| --- | --- | --- | --- |
| Head | 90 mmHg | | |
| Heart | 90 mmHg | | |
| Waist | 90 mmHg | | |
| Feet | 90 mmHg | | |

12. Fill in the chart for the standing patient::

| STANDING PATIENT | Blood Pressure | Hydrostatic Pressure | Measured Pressure |
|---|---|---|---|
| Head | 90 mmHg | -20 mmHg | |
| Heart | 90 mmHg | | |
| Waist | 90 mmHg | 40 mmHg | |
| Feet | 90 mmHg | 80 mmHg | |

# When a person breathes in…

The diaphragm moves ___________________. Which causes an increase in __________________ pressure and a decrease in __________________ pressure.

This causes return  blood blood from the head and arms to ___________________ and return blood flow from the legs and abdomen to __________________.

# When a person exhales...

The diaphragm moves ____________________.

Which causes an increase in ____________________

pressure and a decrease in ____________________

pressure.

This causes return  blood blood from the head and

arms to ____________________ and return blood

flow from the legs and abdomen to

____________________.

# Section 18.7 Nerd Check!

1. What is the definition of hemodynamics?
2. What is volume flow rate?
3. What is velocity?
4. How is velocity different from speed?
5. What is viscosity?
6. What unit is viscosity measured in?
7. What term means too few RBCs? Too many?
8. What blood test tells us the percentage of RBCs?
9. How does pressure affect fluid flow?
10. What happens if the pressure on either side of a fluid is equal?
11. What are two things that exert pressure on the circulatory system?
12. What are the general units of pressure and what is an example?
13. What is created when there is a change of pressure from one side to the other?
14. How does fluid like to flow?
15. What letter represents volumetric flow rate?
16. How does a pressure change affect flow rate?
17. How does the resistance affect flow rate?
18. What is an example of flow rate in your home?
19. What factors are part of resistance?
20. What will happen to resistance if viscosity increases?
21. What will happen to resistance if the length of the tube increases?
22. What will happen to resistance if the radius increases?
23. What factors will cause flow rate to decrease?
24. What does Poiseuille's equation tell us?
25. What are two types of flow?
26. What are the three subsets of laminar flow?
27. What are streamlines?
28. How is laminar plug flow defined in regards to streamlines?
29. Where is plug flow often seen?
30. How is laminar parabolic flow described in regards to streamlines?
31. Where is laminar parabolic flow seen ?
32. What is distrurbed flow?
33. How is turbulent flow defined in regards to streamlines?
34. When do we see turbulent flow?

35. What are eddies and votives?
36. What sound does laminar flow have?
37. What is it called when you can hear turbulent flow?
38. What is it called when you can see turbulent flow?
39. What is Reynold's Number?
40. What value predicts laminar flow?
41. What value predicts Turbulent flow?
42. How is pulsatile flow described?
43. Where is pulsatile flow seen?
44. How is phasic flow described?
45. Where is phasic flow seen?
46. How is steady flow described?
47. What is the law of conservation?
48. What are the 3 most common ways the circulatory "loses" energy?
49. How does viscosity affect energy?
50. What type of energy does friction get turned into?
51. How does inertial energy loss factor into the circulatory system?
52. What is a stenosis?
53. What are the 5 things that occur in a stenosis?
54. What is Bernoulli's Principle?
55. Where is pressure lowest and kinetic energy highest?
56. What is hydrostatic pressure?
57. How does gravity, height and density affect hydrostatic pressure?
58. Where is hydrostatic pressure 0 in the body?
59. WHere is hydrostatic pressure negative in the body?
60. WHere is hydrostatic pressure positive in the body?
61. Why do we take blood pressure measurements at the upper arm?
62. What unit is hydrostatic pressure expressed in?
63. How do we calculate measured pressure?
64. How does hydrostatic pressure change in the supine patient?
65. Through what vessels does blood circulate through?
66. What are the three layers of vessels?
67. Which vessel is more muscular?
68. How can arteries change their size?
69. How can veins change their size?
70. When vessels change size, how does it affect flow?
71. What are the 3 ways in which veins move blood back to the heart?
72. What happens to blood flow in the arms and legs when a person inhales?
73. What happens to blood flow in the arms and legs when a person exhales?