Lesson Title	10. & 11. Blood Pressure (Problems and Lab)
Lesson Designer	Peter Dufner
Standards	☑ CCSS ☑ NGSS ☐ ASCA ☐ Other HS-PS2-1 Motion and Stability: Forces and Interactions. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. HS-PS2-6 Motion and Stability: Forces and Interactions. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. HS-PS3-2 Energy. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
Learning Objectives	Students will be able to: • Describe blood pressure in the body • Explain how a medical professional reads blood pressure

Timeline	Duration
Day 1: Pressure notes and worksheet (45 minutes) Day 2: Blood Pressure Activity (45 minutes) Day 3: Blood Pressure Worksheet (45 minutes)	Three 45-minute lessons

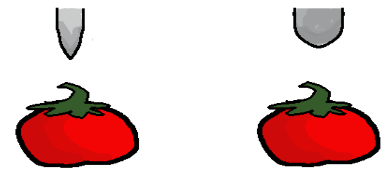
Teaching Strategies/Student Actions	Monitoring
1. Students can be given the notes sheet to read for information from, or the instructor can just use the notes as a basis for the necessary information. The pressure worksheet will assess student knowledge on pressure and basic fluid dynamics. (Bernoulli's principle is excluded) 2. The blood pressure activity is an in-person activity requiring a sphygmomanometer and stethoscope per group, focusing on measuring and understanding blood pressure. 3. The final worksheet is a synthesis of the fluid pressure calculations and the blood pressure experience, asking students to link the two concepts mathematically and conceptually. This can be done as a class, or individually as either homework or classwork.	• Teacher monitors student progress • Teacher facilitates discussion • Teacher questioning

Product Description	
Evaluation	Students will calculate pressure and describe basic fluid dynamics. Students should be able to take blood pressure using the proper equipment, and explain what that means on a fundamental level through the completion of worksheets and laboratory.

Resources and Materials	Additional Notes
• Pressure notes • Pressure worksheet • Blood pressure activity • Blood pressure worksheet	

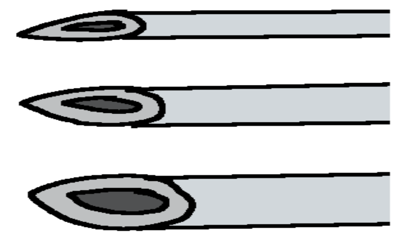
Pressure Notes

<u>Pressure</u> (P) is created by applying a force (F) to an Area (A). The greater the force applied, the larger the pressure created, and the smaller the area applied to, the greater the pressure created. This is why needles use such a fine tip instead of a large point. This is also the same reason that you should keep your knives sharp. A sharp knife will require less force to cut than a dull one.



A dull knife will have a greater cutting area, causing more force to be required to cut than a sharper knife with a smaller cutting area. Which of these tomatoes will be cut cleanly, and which will be squashed instead?

A certain amount of pressure is required to pierce the skin on a person, and we want to do so with as little force a possible. Less force applied to the body means less damage, and less pain. A fine point needle will cause less force to be required to reach the pressure necessary to pierce the skin successfully.



Smaller area needles require less force to achieve the same pressure.

Pressure can be calculated by using the formula

$$\boldsymbol{Pressure = \frac{Force}{Area}} \text{ or } \boldsymbol{P = \frac{F}{A}}.$$

Pressure is measured in many different units, such as pounds per square inch (psi), pascals (Pa), millimeters of mercury (mmHg), and others. For physics, we most often use Pascals, since that is the SI unit for pressure.

Sample Calculation:

The pressure necessary to pierce human skin is approximately 100 psi (pounds per square inch) or 0.69 N/mm^2. How much force would be necessary for a 24-gauge needle, which has a diameter of 0.566 mm to pierce the skin?

Given Information:	Known Formula:
$Pressure\ (P) = 0.69\ N/mm^2$ $Force\ (F) = ?$ $Diameter\ (d) = 0.566\ mm$	$P = \frac{F}{A}$ $A_{circle} = \pi r^2$ $r = \frac{1}{2}d$

Calculations:

Notice that we are using all SI units, and ignoring the psi and gauge units. We just need to make sure that all of our units work well together, and if they don't we need to convert to a single system before using and formulas.

Initially we need to calculate the area (A) of the needle point; otherwise we are unable to use our pressure formula of $P = \frac{F}{A}$.

We can first find the radius of the tip by dividing the diameter of the needle in half.

$$r = \frac{1}{2}d = \frac{1}{2}(0.566)$$
$$r = 0.283\ mm$$

Now we can use the area of a circle formula to solve for the cross sectional area that this force will be applied to using $A = \pi r^2$

$$A = \pi r^2 = (\pi)(0.283^2) = 0.25\ mm^2$$

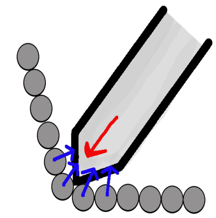
Finally, we can begin solving for our force necessary to pierce the skin. First, we will rearrange our pressure formula to solve for our wanted variable of F, then we will plug in our known variables.

$$A * P = \frac{F}{A} * AF = AP$$
$$F = (0.25)(0.69) = 0.17\ N$$

We find that only 0.17 N of force is necessary to pierce human skin with a 24-gauge needle.

It is important to remember that all of larger visible changes are actually due to the microscopic elements involved. A needle piercing the skin on a person's arm has to break through structures in their skin, moving the atoms that make up the tissues aside so that the needle can enter the vein. Different tissues have different structures, causing them to have different resistive forces to the needle. These resistive forces are what determine how much pressure or force is required to pierce the substance.

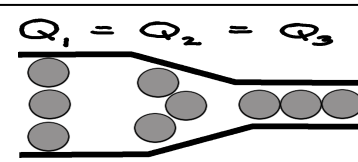
This difference in atomic structure is the ultimate reason why a needle meant for an infant is not appropriate to use on an elephant, and why it is easier for an object to pierce a piece of paper than it is an equivalent piece of steel. The microscopic qualities of each substance define its macroscopic qualities.



A needle pushing must overcome the resistance of the material it is pushing into.

Pressure is created by any force acting on an area, even a force caused by fluids. Fluids should be imagined as any substance that is able to flow, whether it is a liquid or a gas. There are a few key things to keep in mind when discussing fluids:

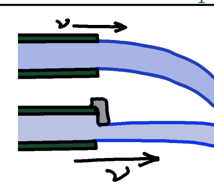
1. Fluids can flow at different speeds within the same system, but they will always have an equivalent flow rate. This means that fluids flowing through a hose will go slower at the larger areas, and faster in the smaller area sections since they always need to have the same amount of fluid flowing through each at the same time.
2. There must be a continuity of flow, meaning any fluid that comes into a system must also leave the system at an equal rate. You cannot have water flow into a hose and get less water out of the hose than went in. This wouldn't make any sense, where would the water have gone?
3. If fluids are within a container they are exerting pressure on all areas of the container. As you use a hose the water is pushing on all sides of the hose, but ultimately leaves through the nozzle since the opening there is the path of least resistance. This is why a weak hose may spring a leak at the weakest point, since the water is always pushing on all sections of the hose.



The flow rate through a system is the same, though the velocity will vary based on area.

These three points are always important to keep in mind when thinking about fluids. We can also perform calculations for each.

1. Flow rate can be calculated as $\text{Mass flow rate} = \text{density of fluid} * \text{Area} * \text{velocity}$ or $Q = \rho A v$.
2. Due to the continuity of flow, we know that the flow rate (Q) at any point in a contained system must be equal to the flow rate anywhere else, so $Q_1 = Q_2$, where Q_1 is the flow rate at one point in the system, and Q_2 is the flow rate at another point in the system.
3. This third point is actually called Pascal's Principle which says that a change in pressure to a system is transmitted equally throughout the system. Pressure added to point 1 (P_1) is also added to any other point 2 in the system (P_2) such that $P_1 = P_2$ or $\frac{F_1}{A_1} = \frac{F_2}{A_2}$.



A partially covered hose has less area for the water to flow through, forcing it to flow faster than an uncovered hose.

Using these ideas of fluid flow and pressure, we can think of a practical application for this such as watering a garden plot with a short hose. If you need to water a plant or garden plot with a hose that doesn't quite reach, you can use your physics knowledge to help you.

The first thing you should do is increase the flow rate by opening the faucet to its maximum. If your flow rate is low, you won't get much water out of the hose no matter what you do. If the water still isn't reaching the garden, you should cover some of the hose with your finger in order to decrease the area that the water can escape from. Since the same amount of water must leave the hose as is coming in, the water is force to flow faster through the opening, letting you spray the water farther.

Water molecules will collide with the covering, adding additional pressure to whatever substance is blocking the outlet.

If you do this, notice that the more area you block with your finger, the more pressure you feel exerted on your finger. This is due to the water molecules colliding with your finger at increasing velocities. Please note that the increased pressure you feel exerted on your finger is not the same pressure that the hose would experience, since your finger is experiencing the forces of all the water molecules being redirected as they collide with it.

Sample Calculation:

Your garden hose has a mass flow rate of 0.63 kg per second and an opening with an area of $5.0 * 10^{-4}\ \mathrm{m}^2$. Water has a density of 1000 $\mathrm{kg/m^3}$. How fast will the water move when it leaves the hose, and how fast would it move if you covered ¾ of the hose end with your thumb?

Given Information:	Known Formula:
$Q_1 = 0.63\ kg/s$ $A_1 = 5.0 * 10^{-4}\ m^2$ $v_1 = ?$ $v_2 = ?$ $\rho_{water} = 1000\ kg/m^3$	$Q = \rho A v$ $Q_1 = Q_2$

Calculations:

We have two questions to answer in this problem: 1) how fast (v) would the water be flowing *without* covering the hose end, and then 2) how fast (v) would the water be flowing while covering 75% of the hose end with our thumb.

Start with the simplest part and solve for v_1, the hose's base flow speed. Looking at our two known formulae, only one of them has velocity at all so we will use the $Q = \rho A v$ equation to solve for v_1. I am going to write the subscript of $_1$ for each quantity to remind myself I am working with the unchanged area of the hose.

$$Q_1 = \rho A_1 v_1$$

Rearrange the formula to solve for your known quantity of v_1

$$\frac{Q_1}{\rho A_1} = \frac{\rho A_1 v_1}{\rho A_1}$$

$$\frac{Q_1}{\rho A_1} = v_1$$

Now we can plug in our known quantities to solve:

$$\frac{(0.63)}{(1000)(5.0 * 10^{-4})} = v_1$$

$$v_1 = 1.26\ m/s$$

Now we can go and solve for the velocity of the water out of the hose when you cover some of it. First we need the resulting area that the water can escape from if you cover ¾ of the hose with your thumb.

$$A_2 = \frac{3}{4} A_1$$

$$A_2 = \left(\frac{3}{4}\right)(5 * 10^{-4}) = 3.75 * 10^{-4}\ m^2$$

Now we know that the flow rate Q_1 from the uncovered hose has to be equal to the flow rate of the partially covered hose Q_2 so:

$$Q_1 = Q_2$$

We can plug in the other formula of $Q_2 = \rho A_2 v_2$ to begin solving for v_2.

$$Q_1 = \rho A_2 v_2$$

Rearrange to solve for the wanted variable of v_2 by dividing both sides by (ρA_2).

$$\frac{Q_1}{\rho A_2} = \frac{\rho A_2 v_2}{\rho A_2}$$

$$\frac{Q_1}{\rho A_2} = v_2$$

Now we can plug in our known quantities and solve for v_2.

$$\frac{0.63}{(1000)(3.75 * 10^{-4})} = v_2 = 1.68\ m/$$

This answer makes sense, since the covered hose should spray faster than the uncovered hose, since the same amount of water must flow through the smaller area in the same amount of time.

Pressure Worksheet

Fill in the blanks in the following section using the words from the word bank provided. No term in the word bank should be used more than once.

Word Bank #1-#5		
Double	Force	Fluid
Pascal	Continuity of flow	Area

1. Pressure is created by applying a ________________to an area.
2. The SI unit for pressure is the ________________.
3. By doubling the force applied to the same ________________, the pressure applied will ________________.
4. Due to the ________________, equal amounts of the fluid must flow in and out at the same time.
5. Pressure due to a ________________is caused by the atoms pushing on the surroundings.

Mark each statement as either (T) true or (F) false. If the statement is false, correct the statement as best you can to make it true.

6. _____ In a closed system, if 100 gallons of water enter per minute, 100 gallons of water must leave the system.
7. _____ Applying a force to a smaller area will create less pressure than applying that same force to a larger area
8. _____ Fluids in a hose have their atoms colliding and pushing out on the entire hose.
9. _____ The mass flow rate must be equal at all points within a closed system
10. _____ By decreasing the area that a flowing fluid can move through, you will decrease the velocity of the fluid.

Answer the following questions by choosing the one best answer to each.

11. Which of the following equations is not correctly written?
    a. $Q=\rho Av$
    b. $P=F/A$
    c. Q_1=Q_2
    d. F_1/A_2 =F_2/A_2

12. If the pressure applied to an area is tripled, what happened to the force being applied to that area?
    a. Nothing, the force must have remained the same
    b. The force must have been increased by 3 times
    c. The force must have been decreased by 3 times
    d. We need more information

13. Which of the following is not a unit for pressure?
    a. Pa
    b. kg/s
    c. Psi
    d. mmHg

14. If you want to decrease the amount of pressure to a surface, which of the following methods will work?
    a. Increase the force applied
    b. Decrease the area that the force is applied to
    c. Increase the force applied and decrease the area applied to equally
    d. Decrease the force applied and increase the area applied to equally

15. If the flow rate of a system must remain constant, what happens in an area where the area decreases?
    a. The fluid will flow faster
    b. The fluid will decrease in density
    c. The atoms won't hit the walls at that point
    d. The flow rate will increase

16. A 20-gauge needle has an outer diameter of 0.908 mm and 0.69 N/mm^2 of pressure is required to pierce the skin of a person.
    a. What is the area in mm^2 of the needle point?

    b. How much force is necessary to pierce the person's skin using this needle?

    c. If the needle point swapped for one with *half the area*, how much force is now necessary to pierce the skin with the slimmer needle?

17. A vein in the human body has an average diameter of 0.9 cm.
    e. What is the average radius of the vein?

    f. What is the average cross sectional area of that vein?

    g. If blood has an average density of 1 g/cm^3 and a mass flow rate of 87.23 g/s through the veins on average, what is the average velocity of the blood?

b) A needle is composed of a hollow tube, with an outer radius and an inner radius. The outer radius determines the size of the puncture into the skin, while the inner radius controls the fluid flow. For this needle the outer diameter is 0.0128 cm larger than the inner diameter of the needle. This needle is attached to a syringe filled with a saline solution with a density of $\rho = 2.61\ g/cm^3$. The syringe has a volume of 0.5 cm^3 and is emptied in 3 seconds.
    a. What is the mass flow rate of the fluid leaving the needle?

    b. The saline solution leaving the needle is moving at 4.60 cm/s. What is the inner area of the needle point?

    c. What is the inner diameter of the needle point?

    d. What is the outer diameter of the needle point?

e. What is the area of the puncture created by this needle?

f. If 69 N/cm^2 is necessary to puncture human skin, how much force needs to be applied to the needle point to successfully puncture the skin before injection?

Blood Pressure Laboratory

Introduction
Throughout your entire body, you constantly have blood being pumped and pushed through your vessels. As the blood flows through you, it pushes outward on the walls of each of these vessels. The body is a complex river of blood flowing through veins and arteries, with the heart at its core. In this activity we will dive deeper into the body systems housing the blood, discuss how we measure blood pressure, and what can impact blood pressure within the body.

Materials
1 sphygmomanometer
1 stethoscope

Body Systems
The cardiovascular system is the body system which includes your heart and blood vessels. The heart is the driving force for your blood flow, without a heart your blood would not course through your body providing oxygen and other important nutrients to your cells around your body. If an area of the body does not receive sufficient blood flow, it will begin to wither and starve.

The heart itself is a large muscle in the chest, composed of multiple chambers which fill with blood. This heart is the pump for your circulatory system, squeezing to push blood out into the rest of your body. In a human body, the heart has four chambers. There is a right and left atrium, which are thinner walled chambers in the top half of the heart. The atriums, just like an atrium in a building, are meant for receiving the blood into the heart. On the bottom half of the heart is the right and left ventricles. These ventricles have thicker walls and are more muscular than the atriums because they are responsible for providing the force to push the blood through the rest of the body. Both ventricles squeeze at the same time to keep your body's steady flow of blood moving.

Arteries are the blood vessels responsible for carrying the blood away from the heart. Like the ventricles, these arteries are thick and muscular in order to withstand the forces of the rushing blood. The blood in the arteries pushes on the sides of the vessels forcefully as it is pumped by the heart, creating a high pressure blood flow moving outward. They are located deeper within the body, and break down into smaller arterioles and capillaries to spread the blood flow throughout the body.

Veins are the other major type of blood vessel in our cardiovascular system. The veins carry blood back to the heart after they have already deposited their nutrients and oxygen to the body tissues. Veins are thinner and more collapsible than arteries, and are often found much closer to the surface of the body than arteries are. Since the blood has already had to flow through the smaller blood vessels spread throughout the body before rejoining the vein, the blood has a much lower pressure in the veins.

Measuring Blood Pressure
Blood pressure can be measured through the use of a blood pressure cuff, or a sphygmomanometer. These devices consist of an inflatable cuff which goes around the arm, a pressure gauge, and some sort of pressure control.

The blood pressure recorded when the heart is contracting; pushing blood out of the heart is called systolic blood pressure. When the heart is at rest between beats, the pressure is lower and called the diastolic blood pressure.

The way a sphygmomanometer works is by first constricting the blood flow, and then gradually releasing it the pressure on the artery. As the blood rushes into the opening when the cuff releases, you should be able to hear the turbulent flow of the blood flowing. As the pressure of the cuff releases, the sound should stop as the blood regains its smooth, laminar flow. The pressure read when the first noise is heard through the turbulent flow is the systolic blood pressure, and the pressure read when the last noise is heard is the diastolic blood pressure.

Measuring Your Blood Pressure in Different Positions

For these instructions we will refer to whoever is getting their pressure taken as the patient. This test will be done three times, with the arm held in three different positions. Rotate who the patient is between tests instead of doing all three on one patient in a row.

> *If you are feeling nervous, uncomfortable, or in any way hesitant about having your own blood pressure read please speak to your instructor about your concerns. Do not proceed with this medical process unless you feel comfortable with having your own body readings taken.*

1. Place the cuff around the patient's *brachial artery* in their right or left arm. This can be found right above their elbow on the inside of the arm.
2. Have the patient sit in a comfortable chair.
   a. For the first test, the patient should rest their arm at about a 90° angle on a surface.
   b. For the second test, the patient should hold their arm upright as best they can while still remaining seated.
   c. For the third test, the patient should let their arm dangle downward.
3. Place the head of the stethoscope just under the edge of the cuff, a little bit above the crease of the elbow on the inside of the arm.
4. Inflate the cuff until either the pressure is read as 150 mmHg or the pulse is no longer heard through the stethoscope. The patient will feel pressure on their arm, this is normal and to be expected.
5. Once ready, slightly open the valve on the pump and allow the pressure to decrease gradually. Do not open it too wide or the process will go too quickly. Listen for the first noise you hear through the stethoscope and record the pressure on the gauge as the **systolic blood pressure**.
6. Listen for the last noise you hear, and record the pressure on the gauge at that time as the **diastolic blood pressure**.

Patient Name		
Arm Position	**Systolic Blood Pressure**	**Diastolic Blood Pressure**
Arm at rest		
Arm straight up		
Arm dangling down		
Average		

Conclusion Questions

1. Why do the chambers of the heart have different structures?

2. Arteries and veins serve similar purposes, but have slightly different structures.
   a. What is the difference in the basic structure between a vein and an artery?
   b. What is the reason for this different to exist?
   c. What might happen if your vein and artery functions were to suddenly be reversed, and the veins were responsible for receiving the blood from the heart instead of the arteries?

3. Why would there be a different pressure recorded when the heart contracts versus when the heart is at rest?

4. Why should your systolic blood pressure always be higher than your diastolic blood pressure?

5. Blood pressure will vary between people.
   a. What are some reasons why different people will have different blood pressures? Please be as specific as you can.
   b. A blood pressure reading is normally reported as the $\frac{systolic\ blood\ pressure}{diastolic\ blood\ pressure}$ such as 120/80. These numbers should be in mmHg.
      i. If your sphygmomanometer did not report your blood pressure in mmHg, convert to mmHg now using the conversion table provided.
      ii. What was your blood pressure reading for each position?
         1. Arm up:
         2. Arm at side:
         3. Arm down:
      iii. What was your average blood pressure reading?
      iv. Did changing the position of your arm change your blood pressure in any significant way? (yes/no)
      v. If yes: How did position change your blood pressure reading, and why do you believe this occurred?
      vi. If no: Why did changing the position and height of your arm not affect your blood pressure reading?

Pressure Conversions
1 mmHg = 133.322 Pa
1 mmHg = 0.019 psi
1 mmHg = 1 Torr

Blood Pressure Worksheet

Fill in the blanks in the following section using the words from the word bank provided. No term in the word bank should be used more than once.
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Word Bank #1-#5		
Systolic	Pressure	Veins
Blood	Heart	Walls
Arteries	Thick	Contracts

1. Blood flows from the ______________, into arteries, to the capillaries, and then into the ________________ before returning back to the heart.
2. The _________________ have high pressure blood inside them, causing them to have _________________ walls.
3. The __________________ blood pressure is the pressure recorded when the heart ___________________.
4. A region subject to higher _________________ will experience higher force than a lower one.
5. Blood pressure is caused by the _________________ pushing outward on the _________________ of the blood vessels due to the pressure caused by the heart.

Mark each statement as either (T) true or (F) false. If the statement is false, correct the statement as best you can to make it true.

6. ______ A sphygmomanometer is used to record blood pressure.
7. ______ The systolic blood pressure is recorded when you first hear a noise from a stethoscope after releasing the pressure cuff.
8. ______ When recording blood pressure the noise you hear through the stethoscope is the blood rushing through the blood vessel.
9. ______ Blood pressure should be measured from a vein, not an artery, since it has direct blood flow from the heart.
10. ______ Blood pressures are normally reported in Pascals in the form of systolic/diastolic.

Answer the following questions by choosing the one best answer to each.

11. Which of the following would not result in greater blood flow (Q) through a blood vessel:
    a. A restricted vessel, such as one filled with plaque
    b. A larger heart
    c. Less dense blood
    d. Faster blood flow

12. Having an injury can open a blood vessel and allow blood to leave the closed vessel and exit the body. Blood will flow out of the body and into the air because the blood is under higher pressure inside the body than the atmospheric pressure keeping it in. Which would be the most dangerous to have injured?
    a. An artery
    b. A vein
    c. A capillary
    d. They're all the same

13. A classmate reports that their blood pressure is 75/130. What do you know about this blood pressure reading?
    a. They're healthy since this is within normal range
    b. Their diastolic blood pressure is a little low
    c. Their systolic blood pressure is a little high
    d. They swapped their systolic and diastolic blood pressures

14. Which of the following statements is incorrect?
    a. The heart pushes the blood by applying a force to it
    b. The heart has the highest pressure blood in the body
    c. The blood will lose pressure as it travels through the smaller veins and arteries
    d. The blood will always have the same pressure throughout the body

15. Which chamber(s) of the heart is responsible for pumping blood out of the heart?
    a. Both atrium
    b. Both ventricles
    c. Just the left ventricle
    d. Just the right ventricle

Answer the following questions to the best of your ability, making sure to clearly mark your answer and appropriate unit.

16. A blood pressure reading is recorded as 120 mmHg, but it wasn't written down if it was the systolic or diastolic pressure.
    a. Which type of blood pressure is this reading likely to be?
    b. Explain your reasoning.

17. The blood pressure recorded on a patient's brachial artery was 130/70. This is measured in mmHg.
    a. What was the systolic blood pressure of the patient?
    b. What was the diastolic blood pressure of the patient?
    c. Knowing that 1 mmHg is equal to 133.322 Pa, convert each blood pressure into Pascals below:
        i. Systolic blood pressure in Pa : ____________
        ii. Diastolic blood pressure in Pa: ____________
    d. If the brachial artery has a diameter of 0.004 m, what is the radius of the artery measured?
    e. What is the interior surface area of a 0.01 m long section of the brachial artery, assuming it acts as a hollow tube? Use the formula $A = 2\pi r l$, where l is the length of the section of artery, and r is the radius of the artery.
    f. How much force is acting on that section of artery as the heart contracts? (Systole)
    g. How much force is acting on that section of artery as the heart is at rest? (Diastole)

18. A healthy artery is tested to have a systolic blood pressure of 115 mmHg. Blood has a density of 1000 kg/m^3, and there is a mass flow rate of $6.6 * 10^{-5}$ $\frac{m^3}{s}$ through this section of artery, while moving at 21 m/s.
    a. What is the cross-sectional area of the artery?
    b. What is the radius of this healthy artery?
    c. If plaque builds up in this artery due to unhealthy habits, causing the radius to decrease by 0.001 m, what would be the new radius of open artery?
    d. What would be the new cross-sectional area that blood could flow through?
    e. Assuming the mass flow rate remains the same, what would be the new velocity of the blood through this smaller area?