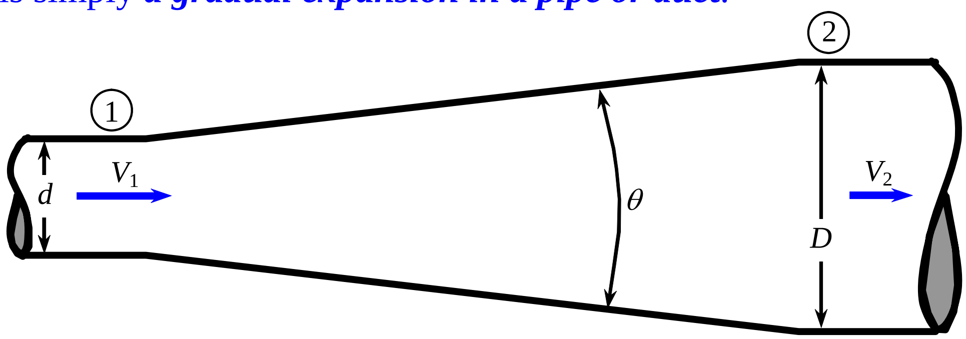
Today, we will:

- Discuss diffusers and do an example problem
- Begin discussing ***pumps***, and how they are analyzed in pipe flow systems

D. Diffusers – Yes, there is a free lunch! → $\boxed{P_2 > P_1}$

1. Introduction.

A ***diffuser*** is simply ***a gradual expansion in a pipe or duct***.



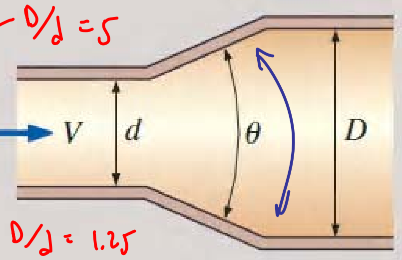
A diffuser is a minor loss, and we can look up its minor loss coefficient K_L in Table 8-4 and other places. [*Note*: Use the larger V (at smaller pipe section) to determine the minor loss.]

Notice that K_L *decreases* as *d/D increases* (*D/d decreases*)

(less expansion)

Expansion (for $\theta = 20°$): — D/d = 5

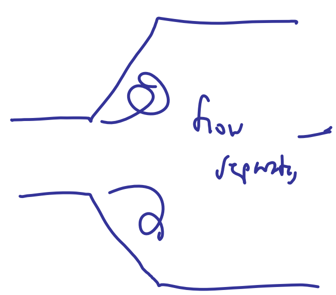
$K_L = 0.30$ for $d/D = 0.2$
$K_L = 0.25$ for $d/D = 0.4$
$K_L = 0.15$ for $d/D = 0.6$
$K_L = 0.10$ for $d/D = 0.8$ — D/d = 1.25



However, even after taking into account the minor loss (and its associated irreversible head loss or loss of pressure), it turns out that the pressure still rises (*increases*) through a diffuser!

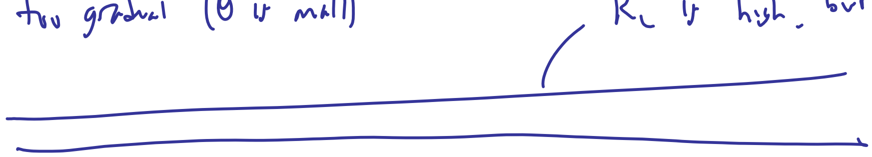
$P_2 > P_1$

Design: • If too sudden (θ is large)



flow separates – $K_L \uparrow$ $P_2 > P_1$ still, but not optimum

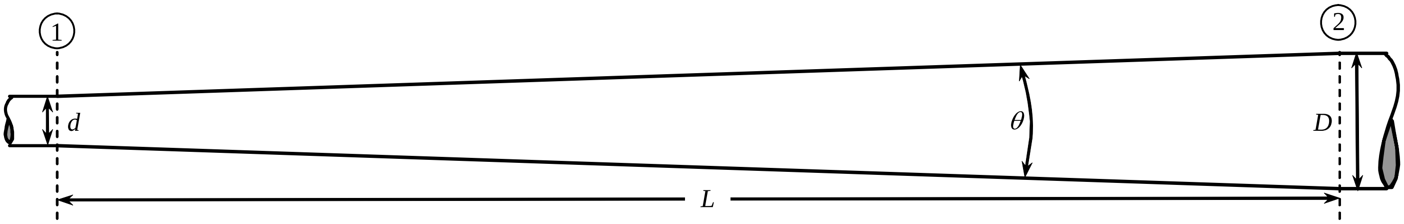
• If too gradual (θ is small)



K_L is high, but because of wall shear (friction)

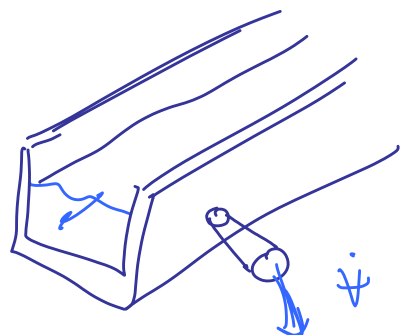
The "best" conical diffuser (high pressure rise with minimal loss) has $D/d \approx \sqrt{8}$ (area ratioof 8), included angle $\theta \approx 4^{\circ}$, and $L/d \approx 25$. [White, F. M., 7th ed., 2009, p. 408.]

Drawn to scale,



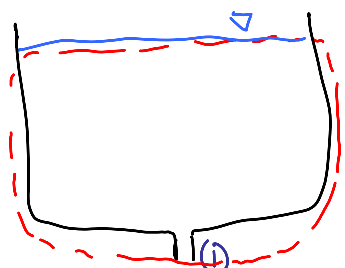
Most real diffusers use $\theta \simeq 10^{\circ}$

Examples: Roman aqueduct system



$\dot{\forall}$ increases with the diffuser

· Draining a tank

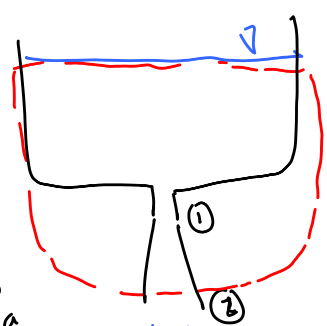


P_a $\quad$ $P_1 = P_{atm}$

V_1

No diffuser

(jet exiting into surroundings) incompressible



$P_2 = P_{atm}$ & $P_2 > P_1$

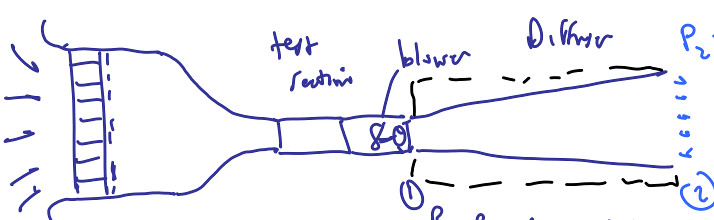
$\therefore\ P_1 < P_{atm}$

P_a

$\ll$ V_2 $\longrightarrow$ $\dot{\forall}$ is greater with the diffuser

$V_2 < V_1$

Eg. Wind tunnel in Fluids Lab (102 Reber)



$P_2 = P_{atm}$

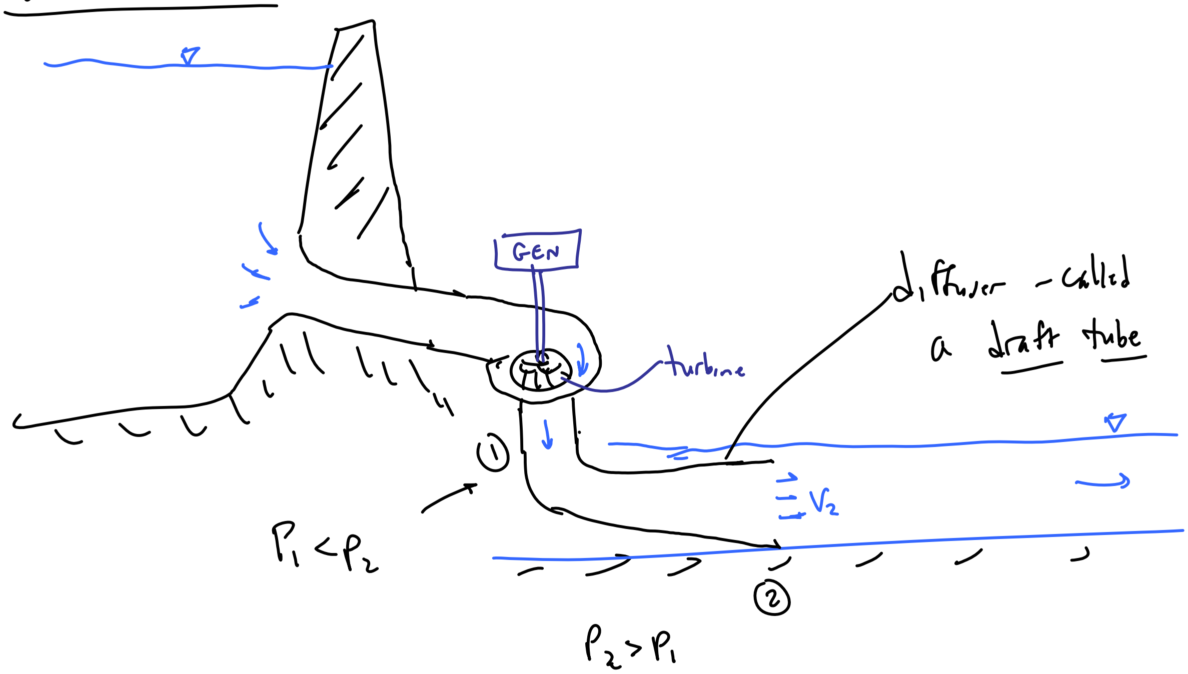
$V_2 < V_1$ $\longrightarrow$ With a diffuser, we "waste" less kinetic energy

$P = P_1$ if no diffuser

With diffuser, $P_1 < P_2 = P_{atm}$ $\rightarrow$ like suction

$\therefore\ \dot{\forall}$ increases.

Hydroelectric dams



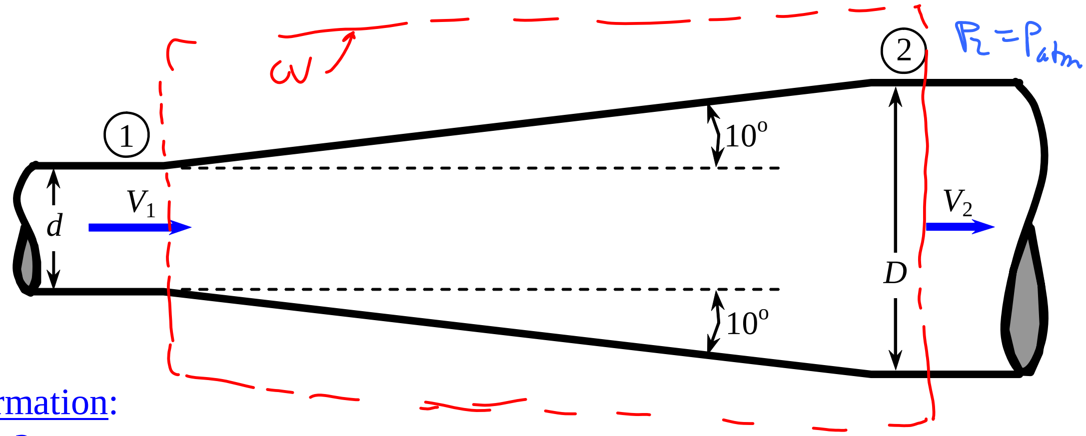
Larger $\dot{\forall}$ through the turbine by adding the diffuser $\rightarrow$ $\underline{\underline{\dot{W} \uparrow}}$

A well-designed draft tube (diffuser) increases the volume flow rate through the hydroturbine & therefore increases the electrical power produced ... for "free"

It is "free" in the sense that the diffuser does not require any power source – it is just part of the flow

Example: Diffuser

Given: Water (ρ = 1000 kg/m^3, μ = 1.00 × 10^{-3} kg/m·s) flows through a horizontal diffuser, as sketched. The flow is fully developed at both locations 1 and 2. The inner diameter changes from d to D through the diffuser. The outlet of the diffuser is open to atmospheric pressure.



Given information:

- d = 1.2 cm
- D = 2.0 cm
- $\theta = 2 \times 10^\circ = 20^\circ$ (θ is the total included angle)
- V_1 = 6.0 m/s
- $P_2 = P_{atm}$
- α_1 = 1.06 and α_2 = 1.06 (fully developed turbulent pipe flow)

To do: Calculate the gage pressure at location 1 and discuss.

$P_{gage,1} = P_1 - P_{atm} = P_1 - P_2$

Solution: *To be done in class.*

• Draw a wise CV.

• Apply cons. eqs Energy eq in head form

$P_2 = P_{atm}$

$$\frac{P_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z_1 + \cancel{h_{pump,u}} = \frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + \cancel{h_{turbine,e}} + h_L$$

$$\boxed{P_{gage,1} = P_1 - P_{atm} = \rho\left(\frac{\alpha_2 V_2^2 - \alpha_1 V_1^2}{2}\right) + \rho g h_L} \qquad (1)$$

• Cons of mass → $V_2 = V_1 \frac{A_1}{A_2} = V_1 \left(\frac{d}{D}\right)^2$

h_L = major + minor losses → here, for my CV, $h_{L,major} = 0$

Look up K_L for the diffuser Table 8-4 @ $\theta = 20°$, $\frac{d}{D} = 0.6$

$\rightarrow$ $K_L = 0.15$

$$\boxed{h_L = K_L \frac{V_1^2}{2g}} \rightarrow \text{Use the higher velocity in our minor loss eq.}$$

Eq. (1) becomes

$$\boxed{P_{gage,1} = \frac{\rho V_1^2}{2}\left[\alpha_2\left(\frac{d}{D}\right)^4 - \alpha_1 + K_L\right]}$$

Ans. in Variable form

#'s $P_{1,gage} = \frac{(1000\ kg/m^3)(6.00\ m/s)^2}{2}\left[1.06\left(\frac{1.2}{2.0}\right)^4 - 1.06 + 0.15\right]\left(\frac{kN \cdot s^2}{1000\ kg \cdot m}\right)\left(\frac{kPa}{kN/m^2}\right)$

$$\rightarrow \boxed{P_{gage,1} = -13.9\ kPa}$$

Notice $P_{1,gage} < 0$

We call this a pressure recovery

changing kinetic energy into pressure energy

E. Turbomachinery (Chapter 14)

1. Introduction and terminology; types of pumps
    a. Positive displacement pumps
    b. Dynamic pumps

- "***Pump***" is a general term for any device that adds mechanical energy to a fluid.
- For liquids, we usually call them "***pumps***".
- For gases, we usually call them "***fans***", "***blowers***", or "***compressors***", depending on the relative pressure rise and volume flow rate.

	Fan	Blower	Compressor
ΔP	Low	Medium	High
$\dot{V}$	High	Medium	Low

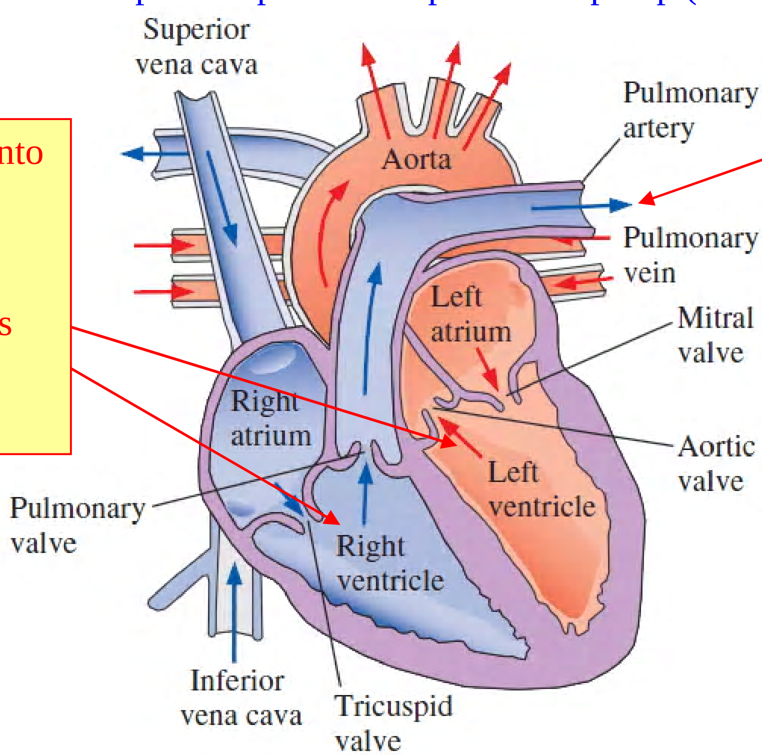
FIGURE 14–3
When used with gases, pumps are called *fans*, *blowers*, or *compressors*, depending on the relative values of pressure rise and volume flow rate.

- There are two basic types of pump:
- ***Positive displacement pumps*** (PDPs) – fluid is sucked into a closed volume, and then the fluid is pushed out.
- ***Dynamic pumps*** – no closed volume is involved; instead, rotating blades called ***impeller blades*** supply energy to the fluid.

Positive Displacement Pumps:

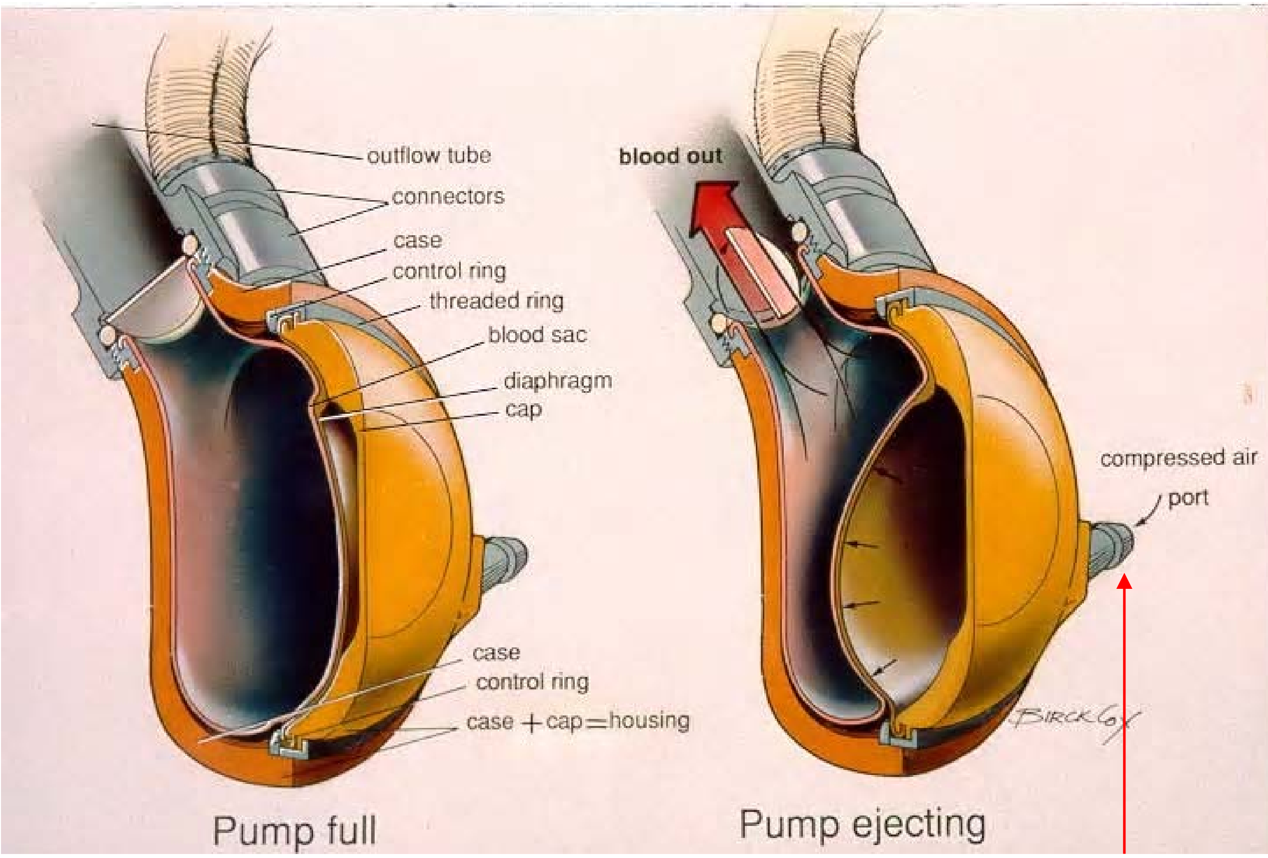
- Your heart is a great example of a positive displacement pump (PDP).

Blood is sucked into the right and left ventricles as they expand. The appropriate valves open and close as necessary.



Blood is pushed out when the right and left ventricles contract. Again, the appropriate valves open and close to enable this.

- Engineers have designed artificial hearts that are also PDPs, and work in similar fashion:

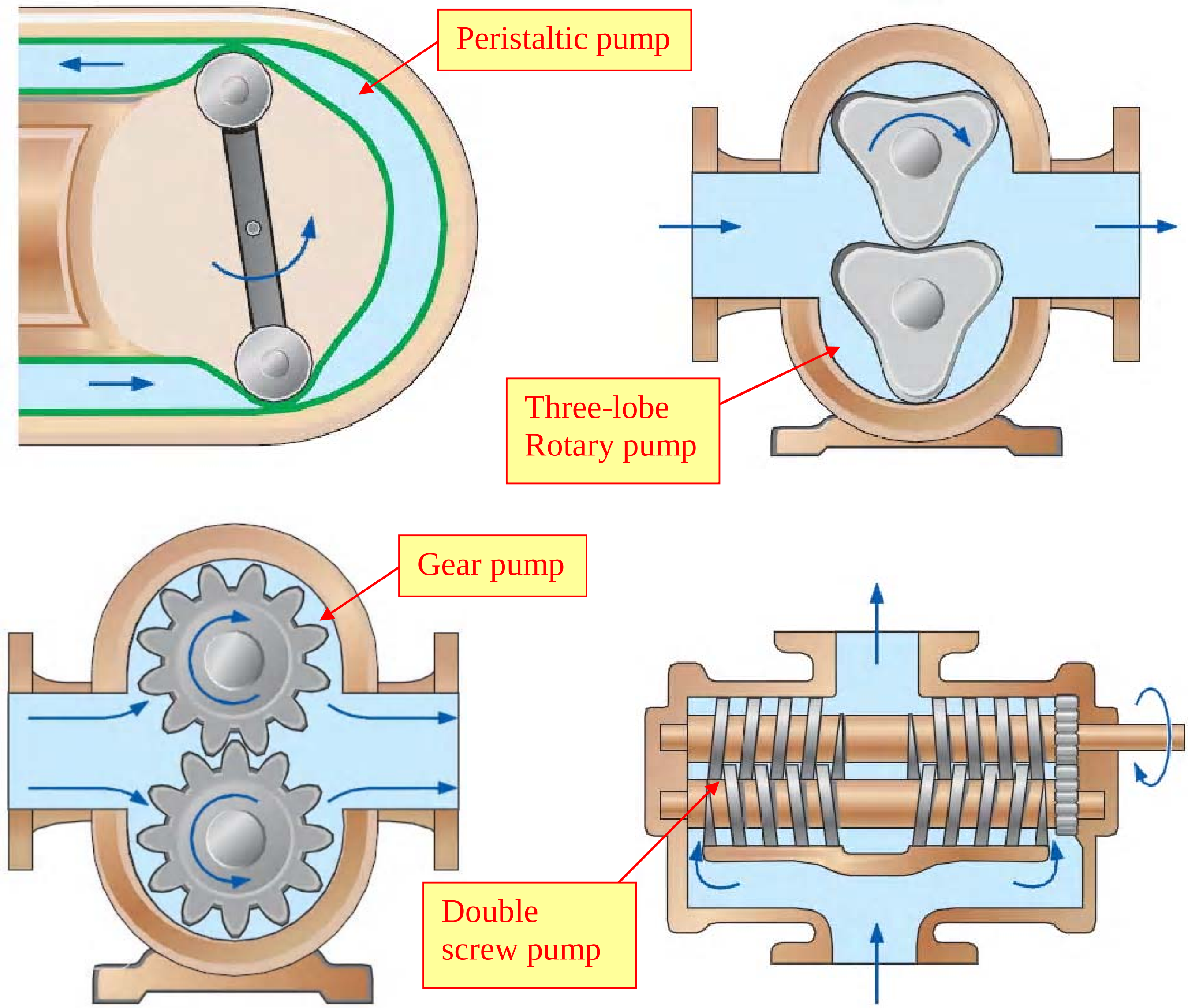


In this design, compressed air is used to expand and contract a bladder to suck in and expel the blood – in much the same way as a bellows.

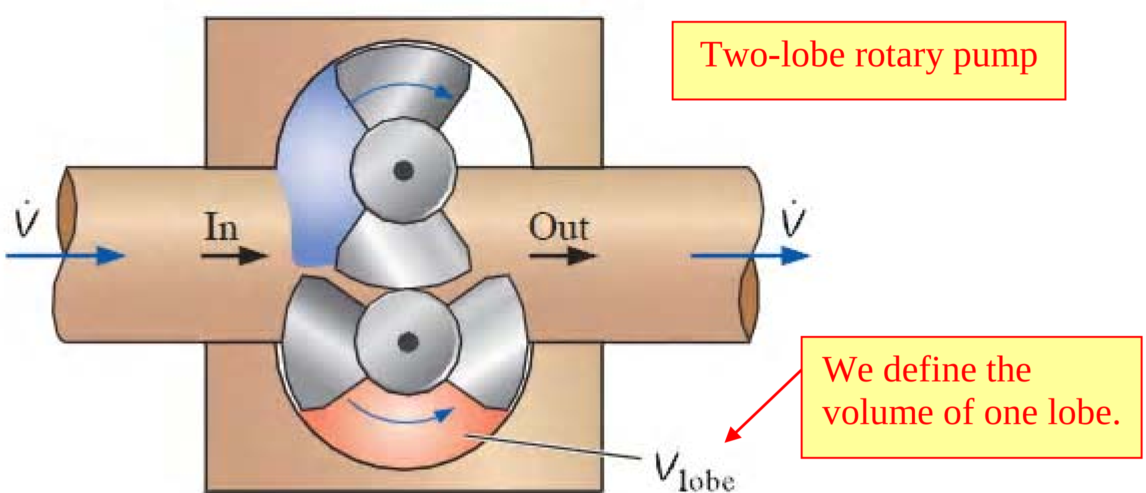
- There are many other examples of positive displacement pump designs:

Bicycle tire pump

Old-fashioned water pump

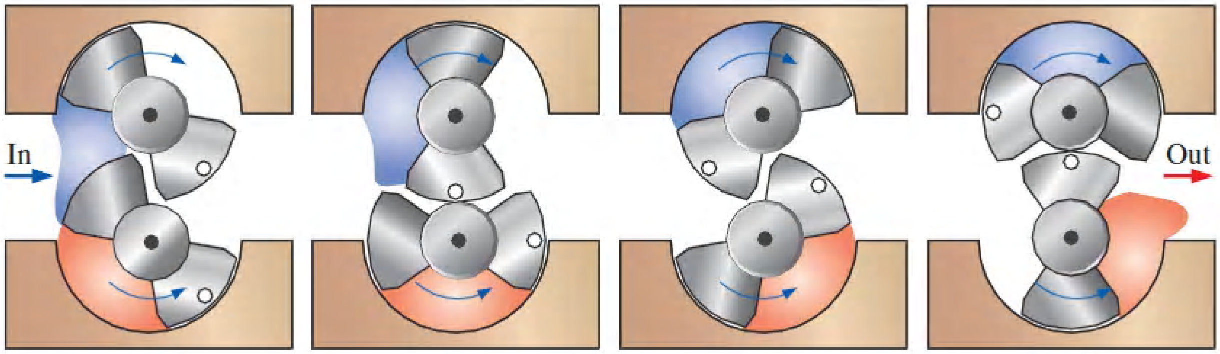


- It is very simple to predict the volume flow rate of a PDP. Let's consider a simple two-lobe rotary pump for illustration:



$$\dot{V} = \frac{\text{Volume displaced}}{\text{rotation}} \cdot \underbrace{\frac{\text{rotations}}{\text{time}}}_{\dot{n}} = \frac{\text{Vol}}{\text{time}}$$

- By analyzing the geometry as the two counter-rotating shafts turn, we see that for each have turn of the shafts (180°), this pump delivers two lobe volumes of fluid.



45° 90° 135° 180°

- For a given rotation rate $\dot{n}$ (rpm) of the pump shaft, we can easily calculate the volume flow rate, assuming no leakage through the small gaps. This is illustrated in the following example problem:

EXAMPLE 14–4 **Volume Flow Rate through a Positive-Displacement Pump**

A two-lobe rotary positive-displacement pump, similar to that of Fig. 14–27, moves 0.45 cm^3 of SAE 30 motor oil in each lobe volume V_{lobe}, as sketched in Fig. 14–30. Calculate the volume flow rate of oil for the case where $\dot{n}$ = 900 rpm.

SOLUTION We are to calculate the volume flow rate of oil through a positive-displacement pump for given values of lobe volume and rotation rate.

Assumptions **1** The flow is steady in the mean. **2** There are no leaks in the gaps between lobes or between lobes and the casing. **3** The oil is incompressible.

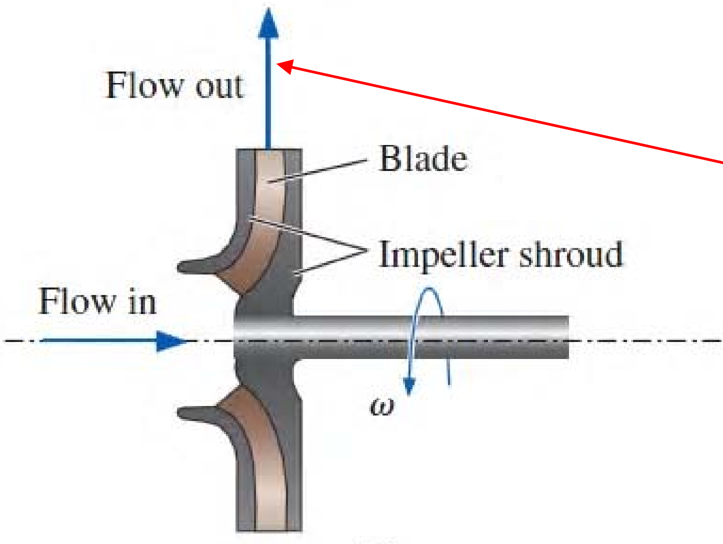
Analysis By studying Fig. 14–27, we see that for half of a rotation (180° for n = 0.5 rotations) of the two counter-rotating shafts, the total volume of oil pumped is $V_{closed} = 2V_{lobe}$. The volume flow rate is then calculated from Eq. 14–11,

$$\dot{V} = \dot{n}\frac{V_{closed}}{n} = (900 \text{ rot/min})\frac{2(0.45 \text{ cm}^3)}{0.5 \text{ rot}} = \mathbf{1620 \text{ cm}^3\text{/min}}$$

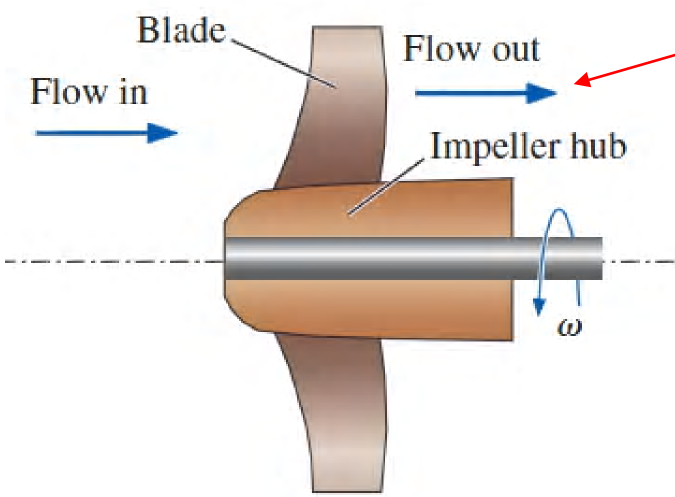
Discussion If there were leaks in the pump, the volume flow rate would be lower. The oil's density is not needed for calculation of the volume flow rate. However, the higher the fluid density, the higher the required shaft torque and brake horsepower.

Dynamic Pumps:

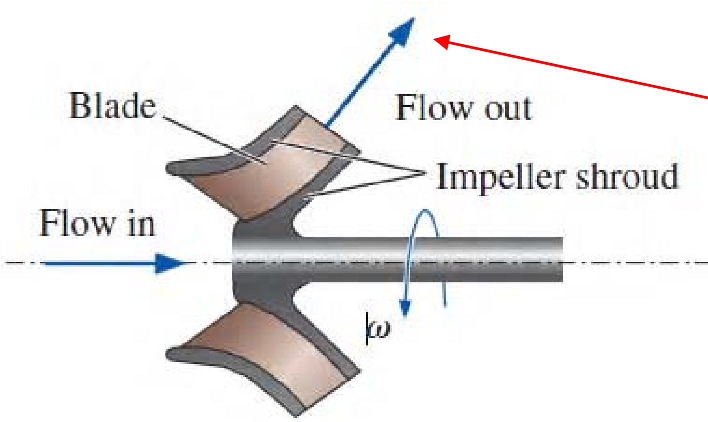
- Dynamic pumps do not have closed volumes. Instead, spinning ***impeller blades*** or ***rotor blades*** transfer kinetic energy and impart momentum to the fluid.
- There are three main types of dynamic pumps: ***centrifugal flow***, ***axial flow***, and ***mixed flow***:



Centrifugal flow pump:
Fluid enters axially and is discharged radially.



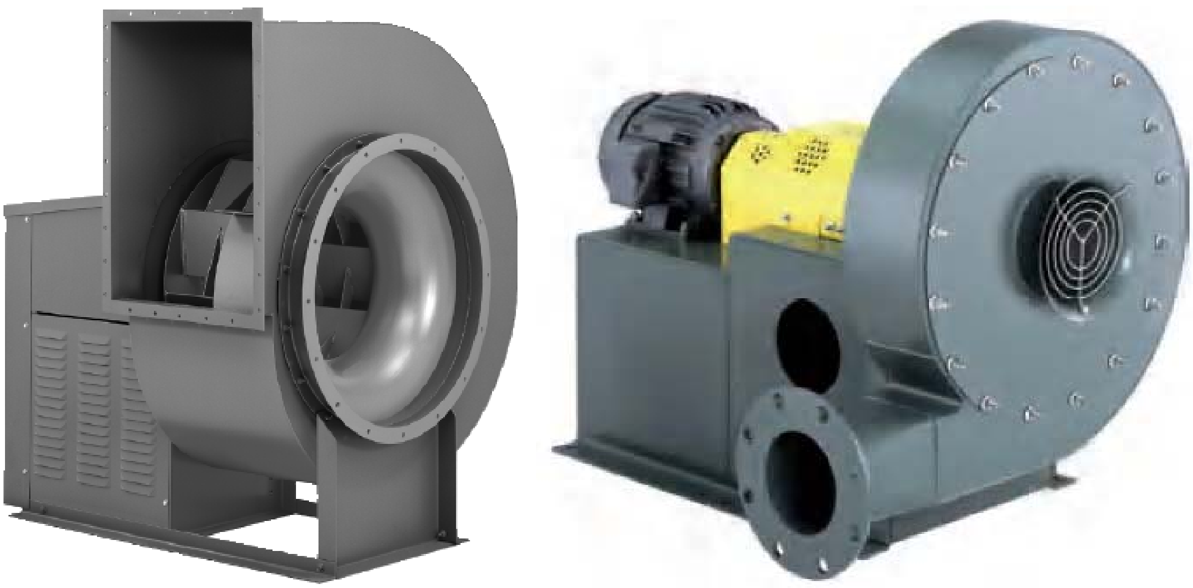
Axial flow pump:
Fluid enters axially and is discharged axially.



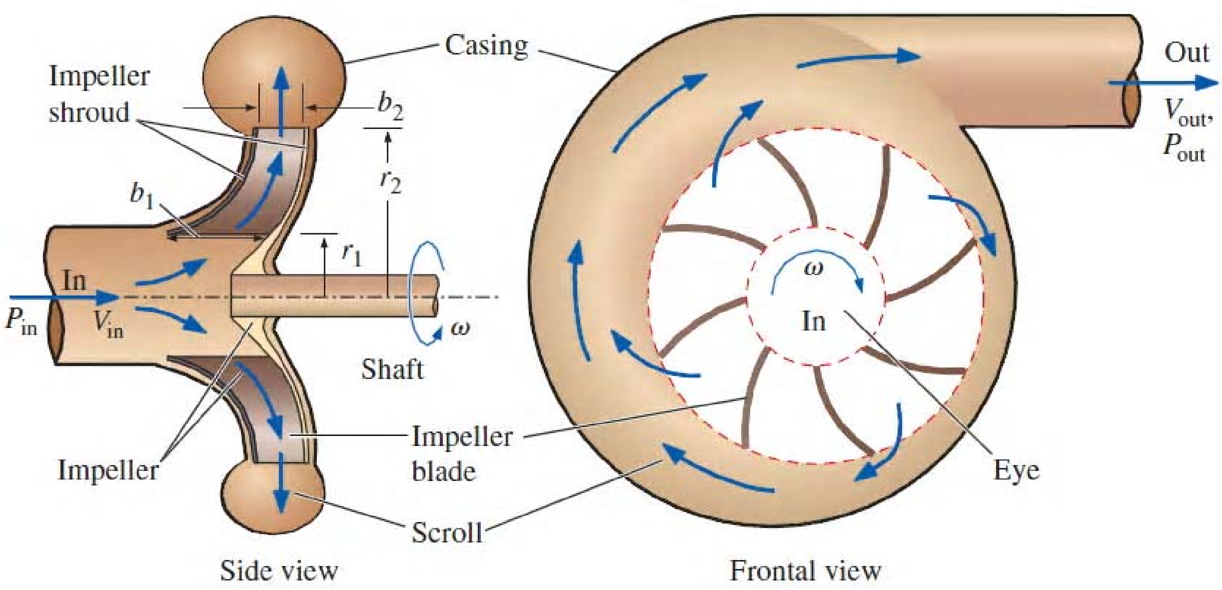
Mixed flow pump:
Fluid enters axially and is discharged at some angle between radial and axial.

- Of these, centrifugal pumps are the most common, and are recognized by their scrolled (snail-like) casing.

Some typical centrifugal air blowers with characteristic snail-shaped scrolls:



- Front and side views of a typical centrifugal pump with backward-inclined blades:



- It is more difficult to predict the volume flow rate induced by a dynamic pump since there are not closed volumes that are easily calculated. Instead, we must use the equations of conservation of mass and angular momentum to analyze the flow and the performance of the pump.