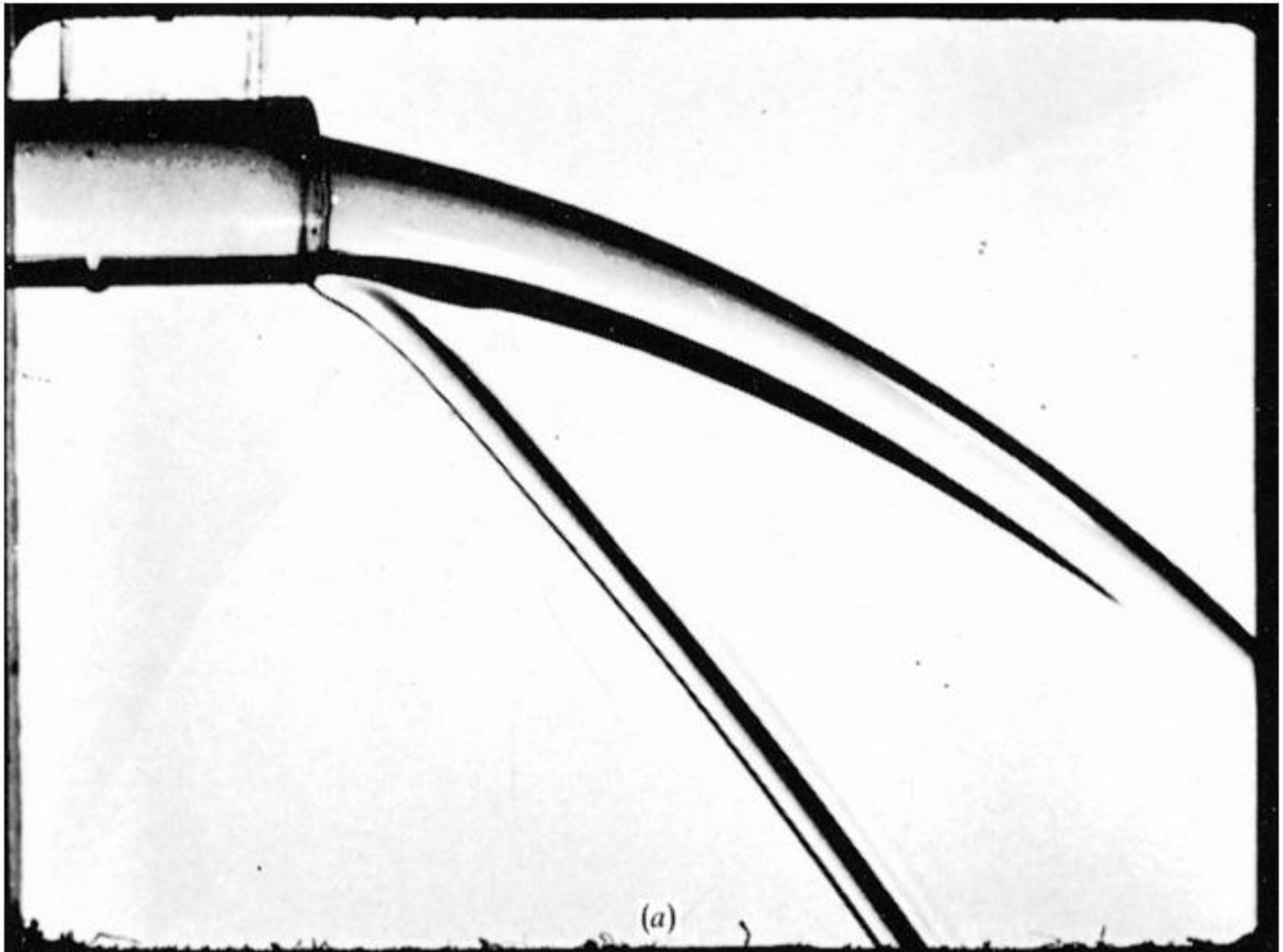
Lab X5 – Reynolds Number

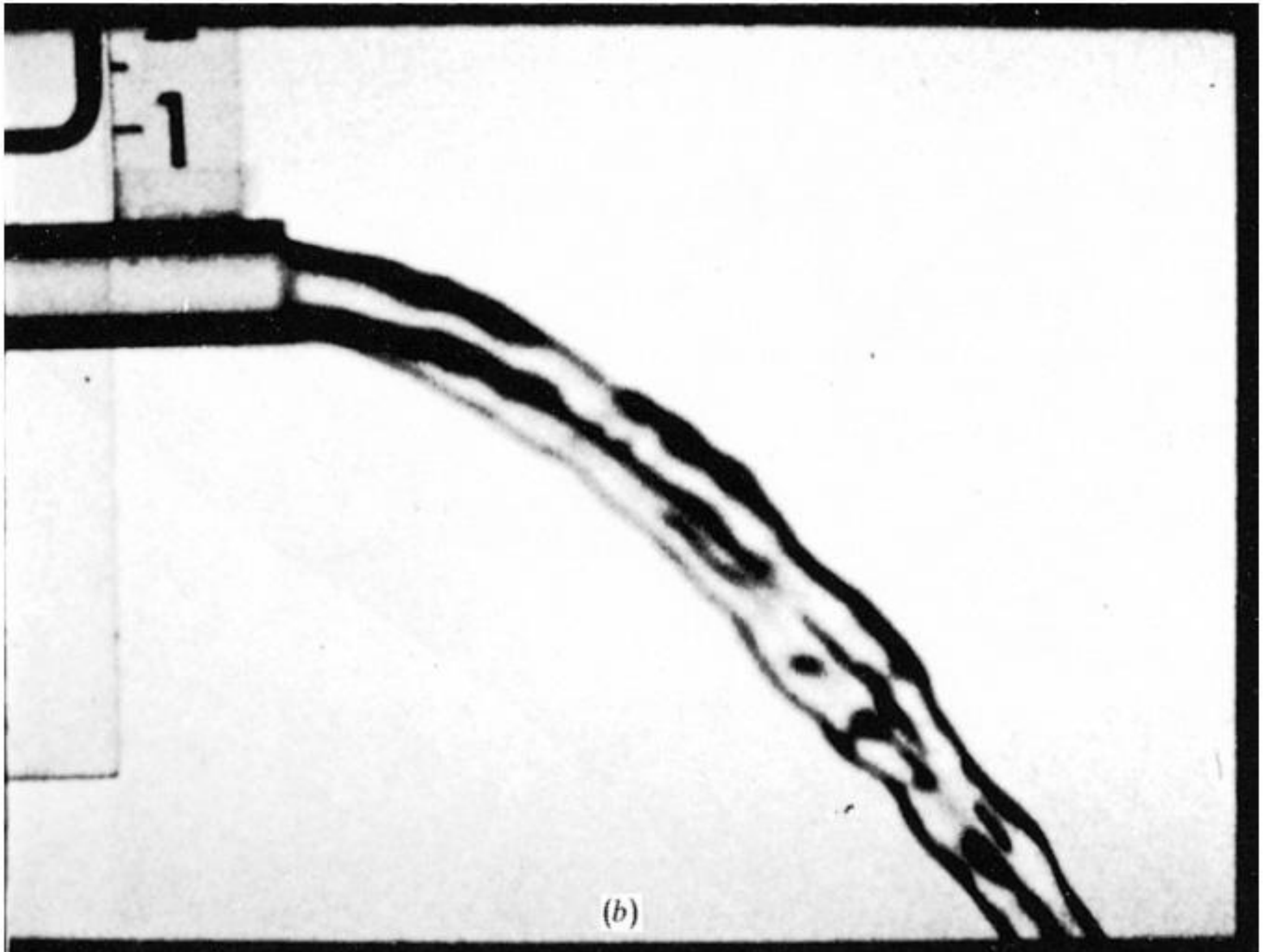
What does turbulence look like?

Figure 6.2a



(a)

What Happened?



(b)

Why does a flow change from laminar to turbulent?

(No one knows after more than a century of research)

(Prof. Lian-Ping Wang is a leader in this research)

When it does is measured by the value of the Reynolds Number

$$Re = V\,D\,\rho\,/\,\mu$$

where

V= average fluid velocity (Q/A)

D= Pipe or tube diameter

ρ = fluid density

μ = fluid viscosity

A man named Osborne Reynolds in England first defined this experimentally in the 1880's .

The defining number is named for him.

Lab Objectives

1. To directly observe and measure laminar, transitional, and turbulent pipe flow, and to quantify the conditions under which these types of flow occur.

1. To apply your experimental observations to a practical process situation.

The Reynolds Experiment

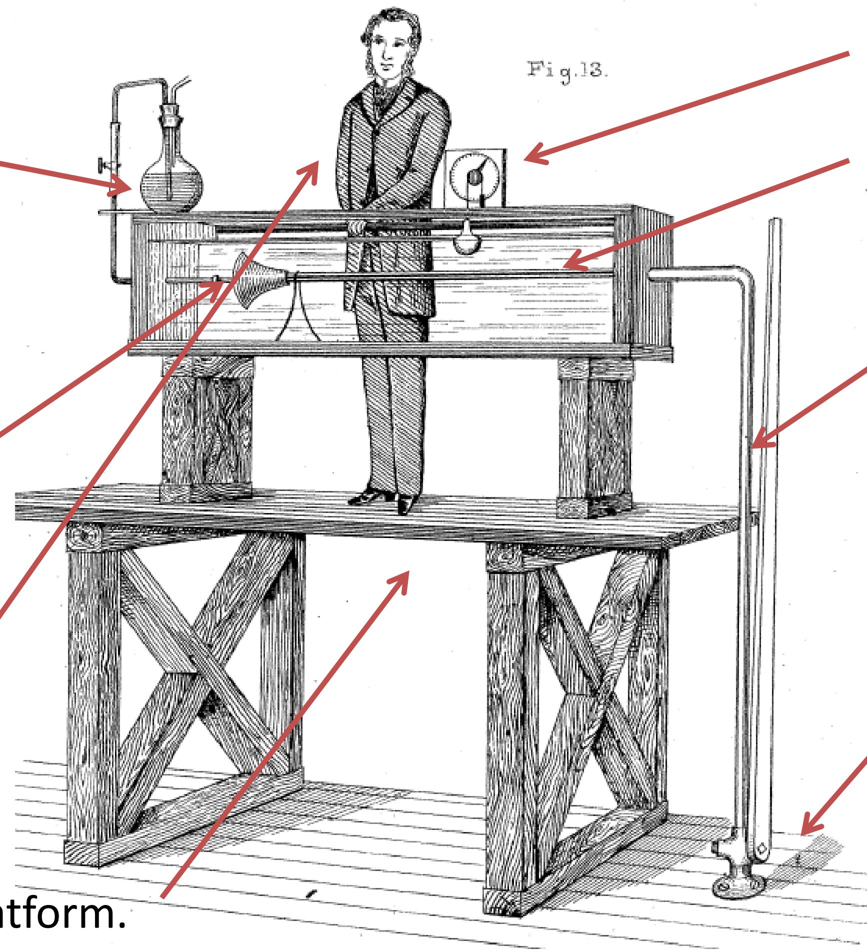


Fig. 3.

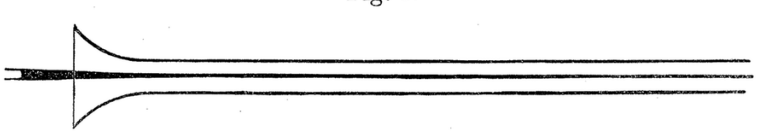
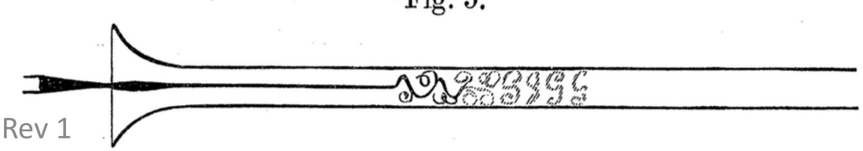
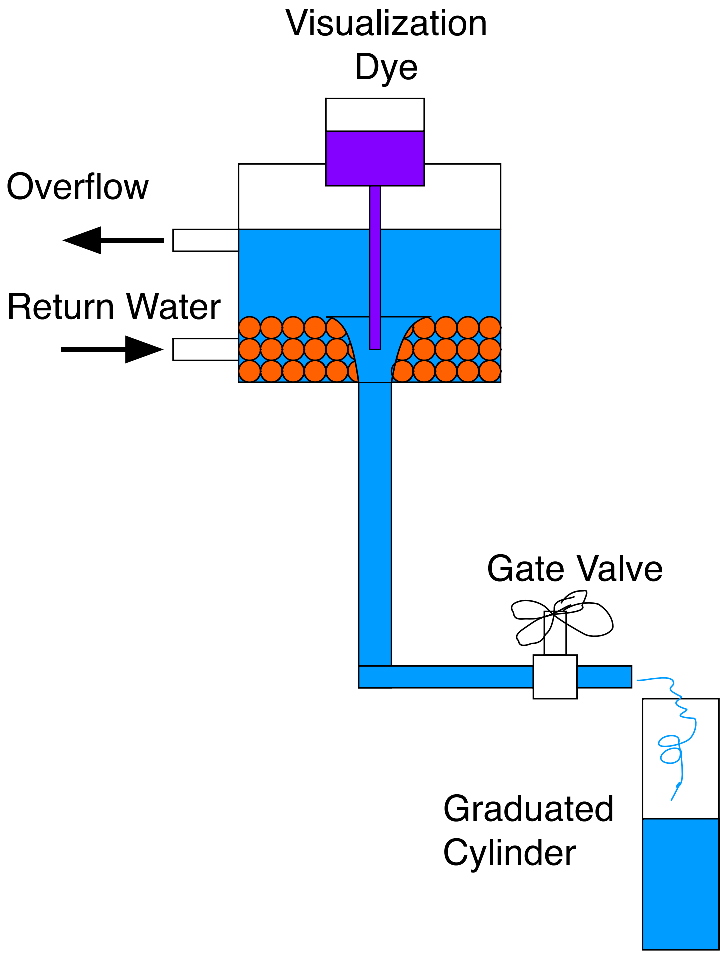


Fig. 5.



Our Apparatus



Transition to Turbulence

- Something that you might have heard:

  White: "Critical Reynolds number = 2300"

- Really: Turbulence isn't an instantaneous phenomena, and transition Re number is not completely universal

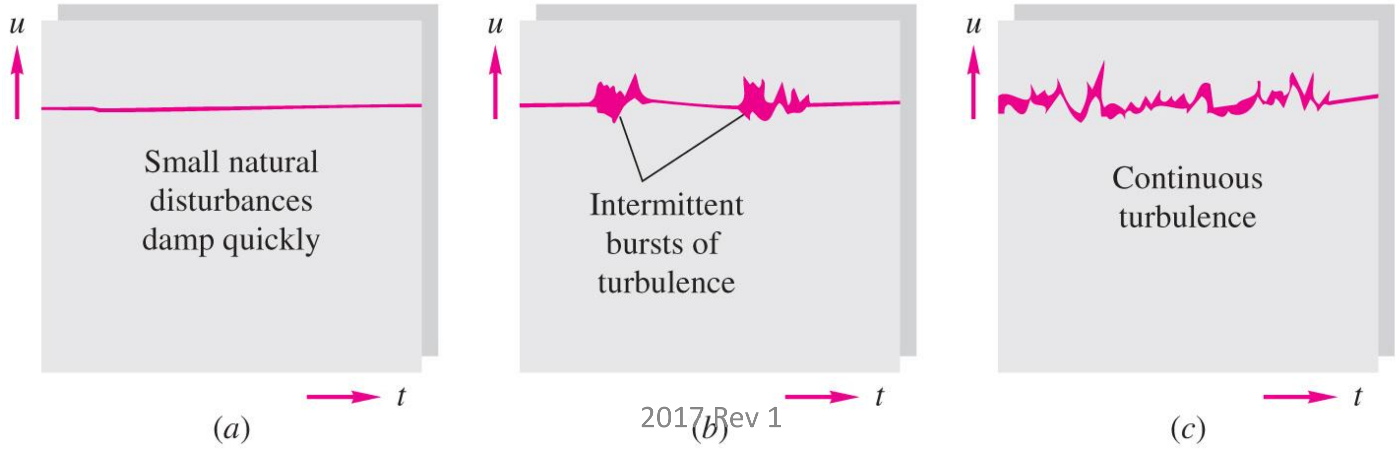
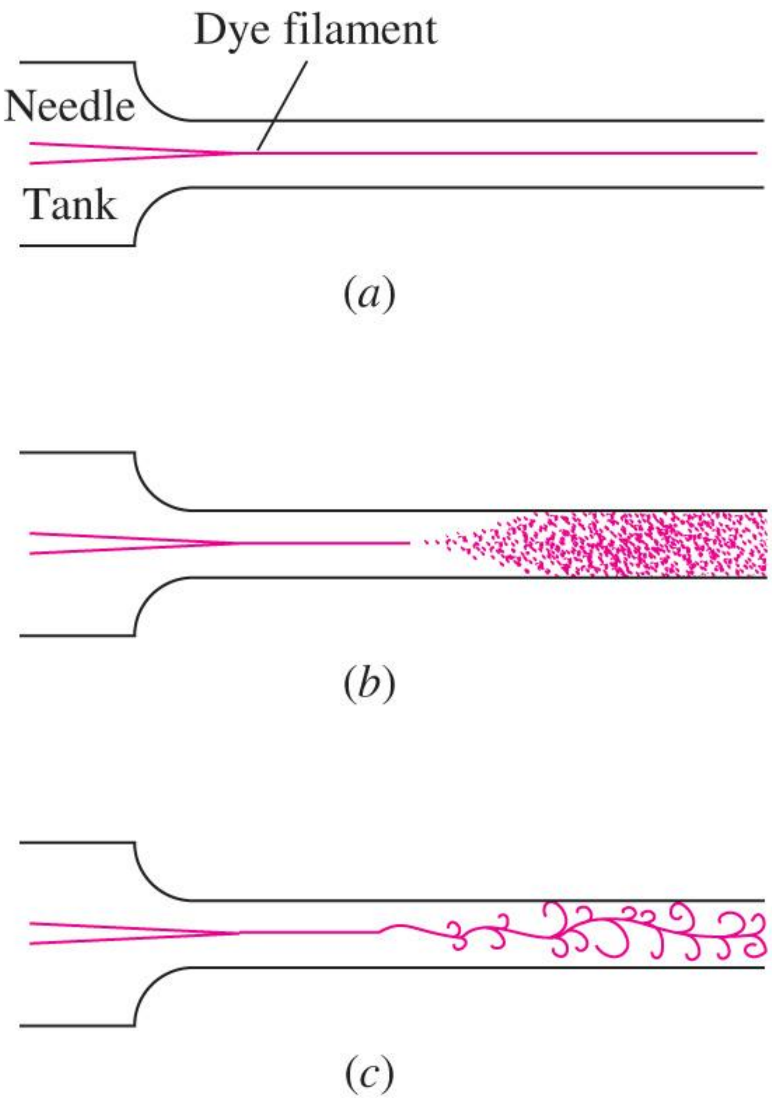


Figure 6.5



Laminar

Turbulent

Snapshot of turbulence

Big whorls have little whorls
Which feed on their velocity,
And little whorls have lesser whorls
And so on to viscosity.

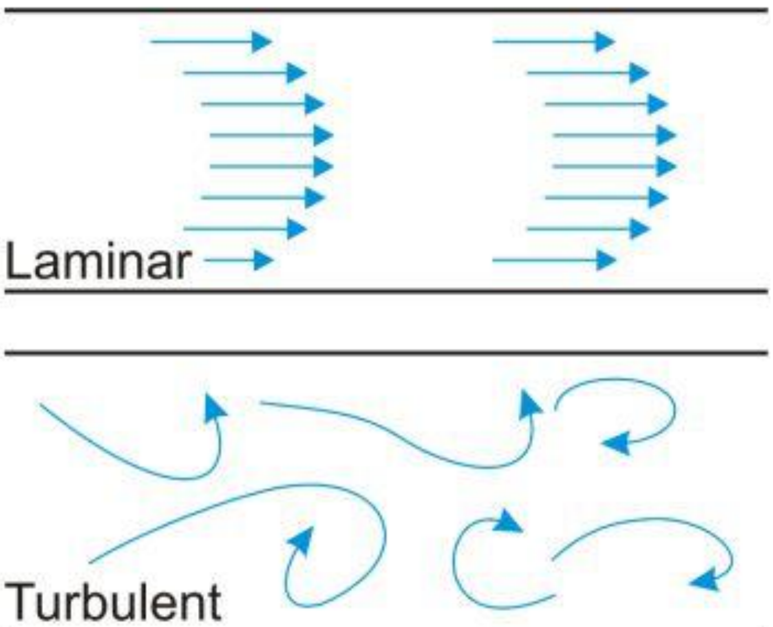
Transition to Turbulence

- <u>Qualitative concept</u>: will small perturbations from laminar flow be damped or grow?
- Reynolds Number

$$\mathrm{Re} = \frac{rUD}{m} \sim \frac{rU^2}{(mU/D)} \sim \frac{rU^2}{(m(du/dr))} \sim \left(\frac{\mathrm{D}P}{t_{viscous}}\right) \sim \left(\frac{\text{Inertial Forces}}{\text{Damping}}\right)$$

- Viscosity acts to damp small perturbations
- Inertia drives perturbations toward destabilization
- The Reynolds number measures this (empirically)

Effect of turbulence (in pipes)



Turbulent Flows Require More pumping power for a given flow rate.

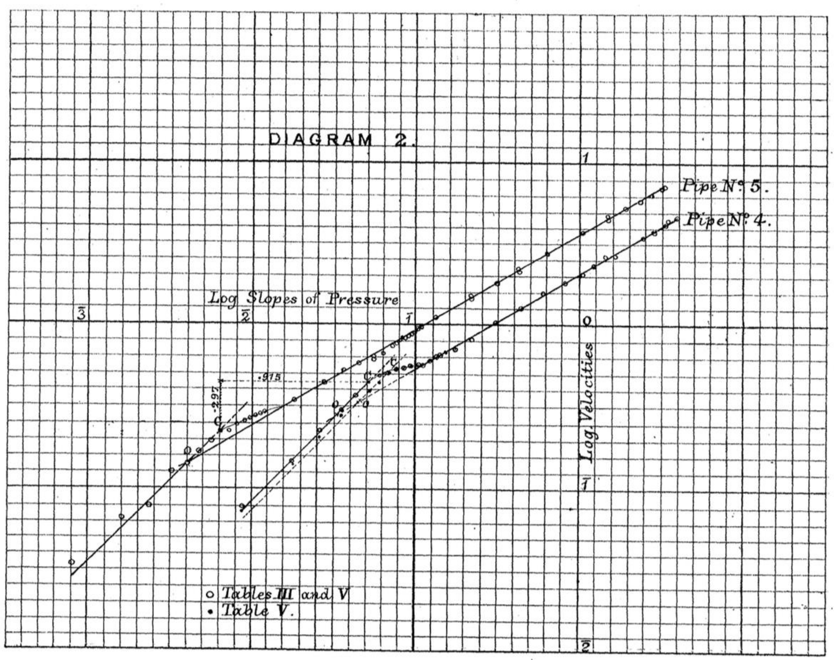
That energy has to go from somewhere!

This shows up as larger pressure losses

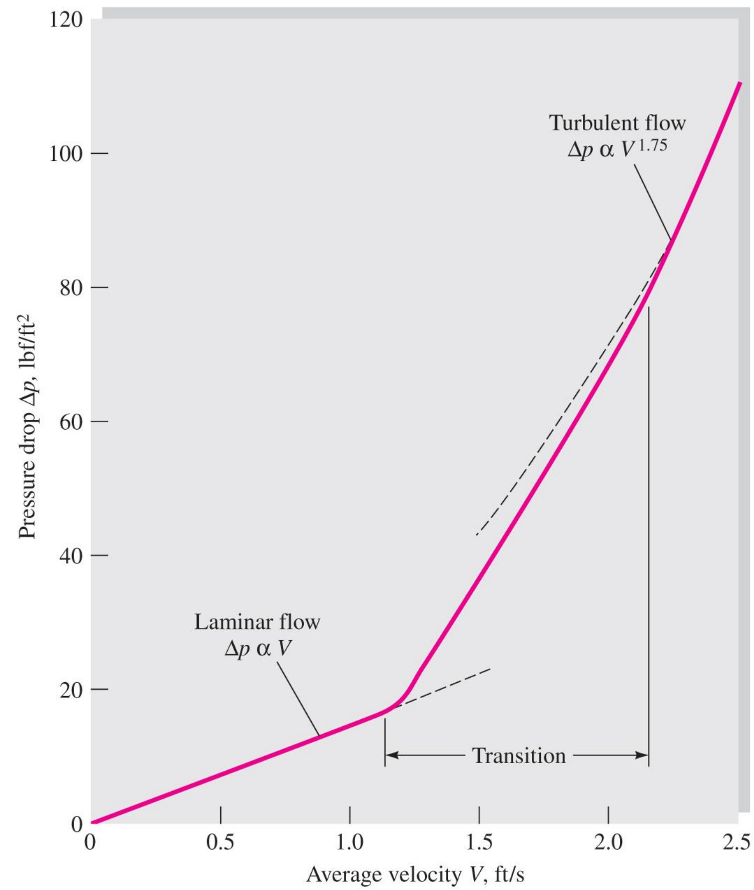
Pressure Loss Behavior: Effect of Turbulence

Reynolds, 1883

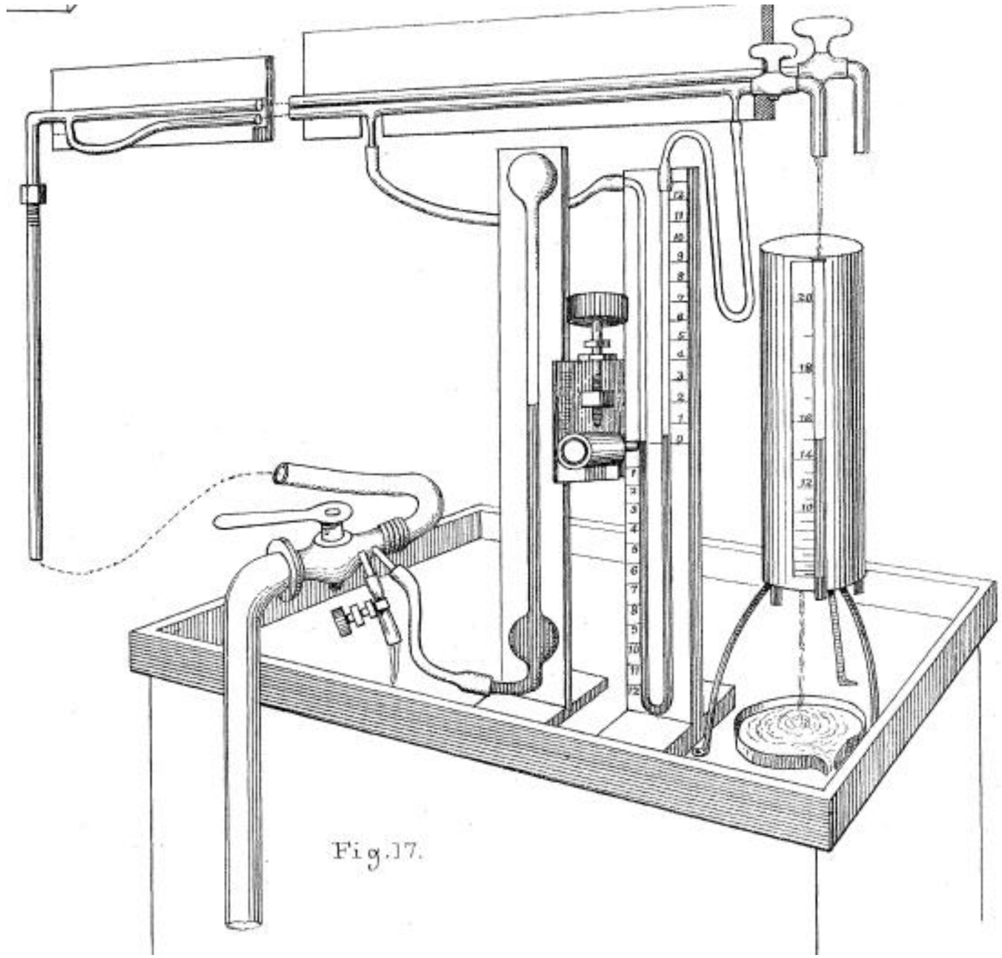
$\log_{10}$ Velocity



$\log_{10}$ Pressure



Pressure Losses



Reynolds Apparatus, 1883

Some details: logarithmic spacing

- Our apparatus can span many orders of magnitude of Re
  $(0 < Re < 20{,}000)$

- If you linearly space your observations:
  Re = [500 2900 5370 7800 102500 ...]
  You'll miss the transition region if you do this!

- <u>Its better to logarithmically space</u>
  Re = [500 740 1100 1650 2450 3600 5400 ...]
  (each one is ~50% bigger than the last, above)

- In your experiment, do this <u>***approximately***</u>.

Some details

- <u>Its better to logarithmically space</u>
  Re = [500 740 1100 1650 2450 3600 5400 ...]
  (each one is ~50% bigger than the last, above)

- Even so, you may not have many points in the transition region... so once you identify the region of interest, go back and take finer spacing (~ 5 points)

- Overall: ~9 coarse observations, ~5 more detailed = ~14 data points. So don't spend too long getting the perfect flowrate.

Transition to Turbulence

- Should other things matter?
  - Roughness of pipe?
  - Shape of entrance region?
  - Room vibrations?
  - Heat addition (boiling for example)

In short, Yes.

Quantifying Pressure Drops: The Darcy Friction Factor

- What should it depend on?

$$\Delta P = function(\rho, V, D, L, \mu, \epsilon \text{ (roughness)})$$

- 7 Variables, 3 Dimensions -> 4 dimensionless numbers

$$\frac{\Delta P}{\frac{1}{2}\rho U^2} = func\left(\frac{\rho U D}{\mu}, \quad \frac{L}{D}, \quad \frac{\epsilon}{D}\right)$$

- But intuition tells us that if we double the length of the pipe, then the pressure drop should double as well

$$\frac{\Delta P}{\frac{1}{2}\rho U^2} = \frac{L}{D} \quad * func\left(\frac{\rho U D}{\mu}, \quad \frac{\epsilon}{D}\right)$$

Quantifying Pressure Drops: The Darcy Friction Factor

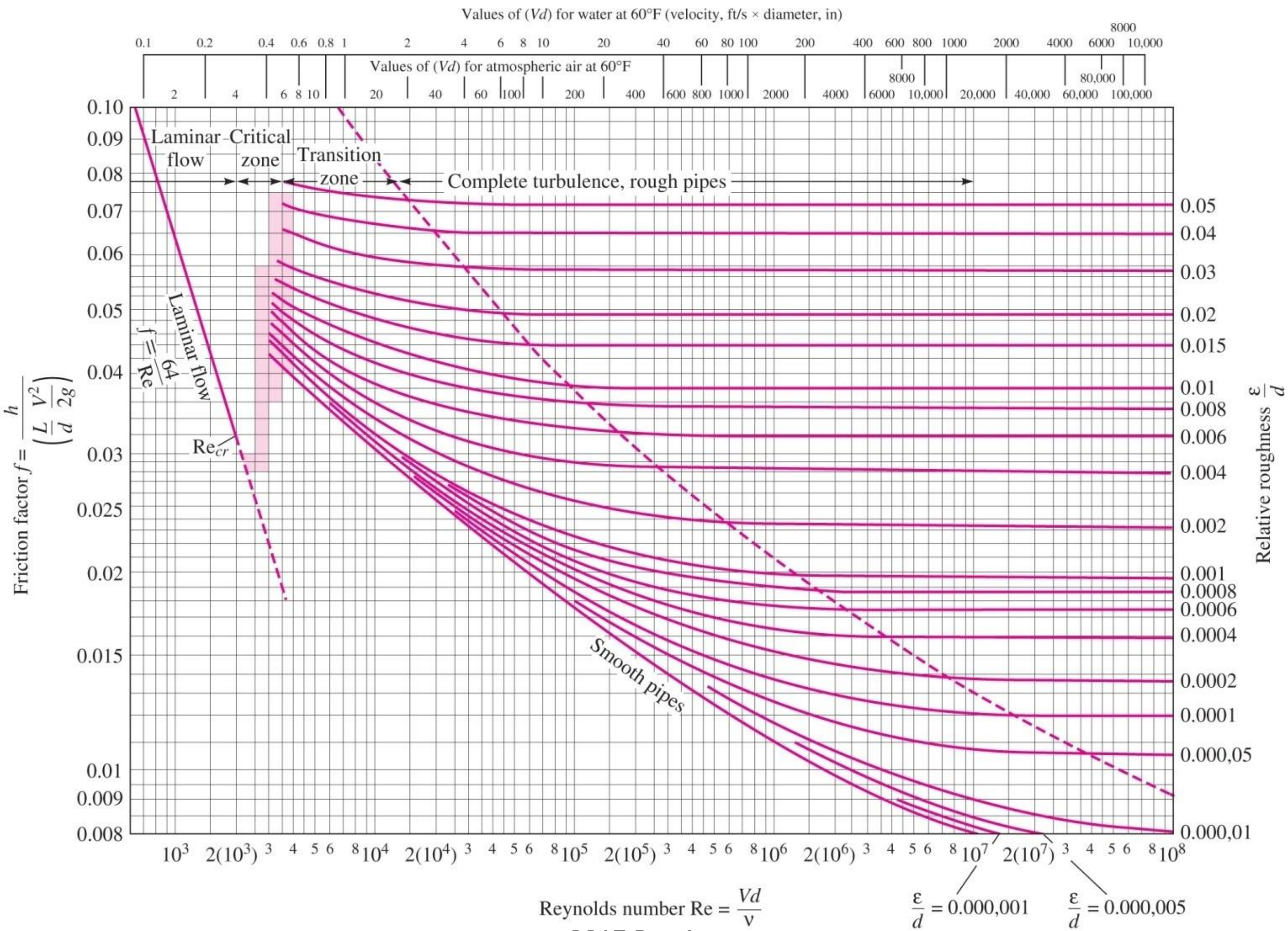
- Darcy "friction factor":

$$\boxed{f \equiv \frac{\Delta P}{\tfrac{1}{2}\rho U^2 (L/D)} = f\left(\mathrm{Re},\quad \frac{\epsilon}{D}\right)}$$

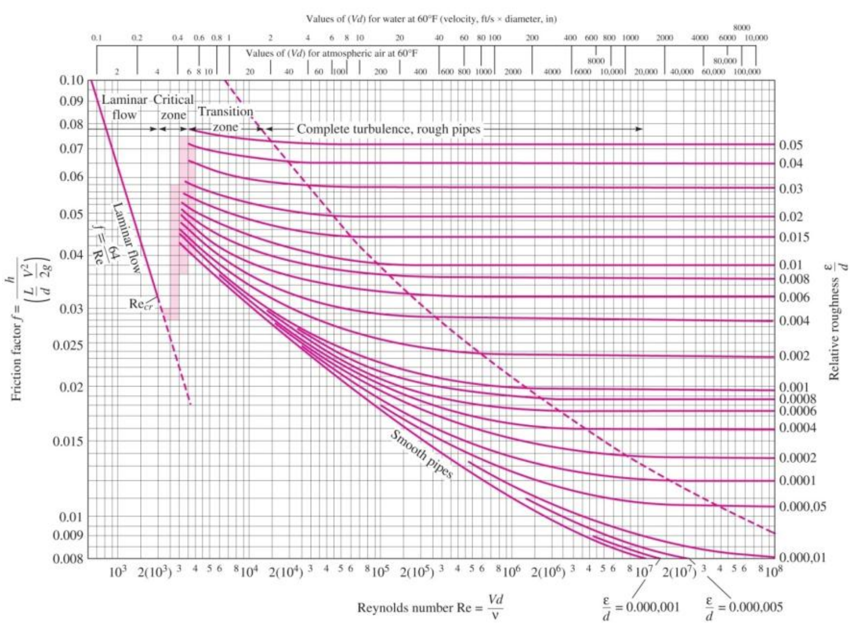
- If we knew $f\left(\mathrm{Re},\quad \frac{\epsilon}{D}\right)$ then we could calculate pressure drop for any flow condition

- This is usually presented as a <u>*Moody Diagram*</u>

The Moody Diagram



The Moody Diagram



- For *smooth pipes*, things are a bit more simple, though:

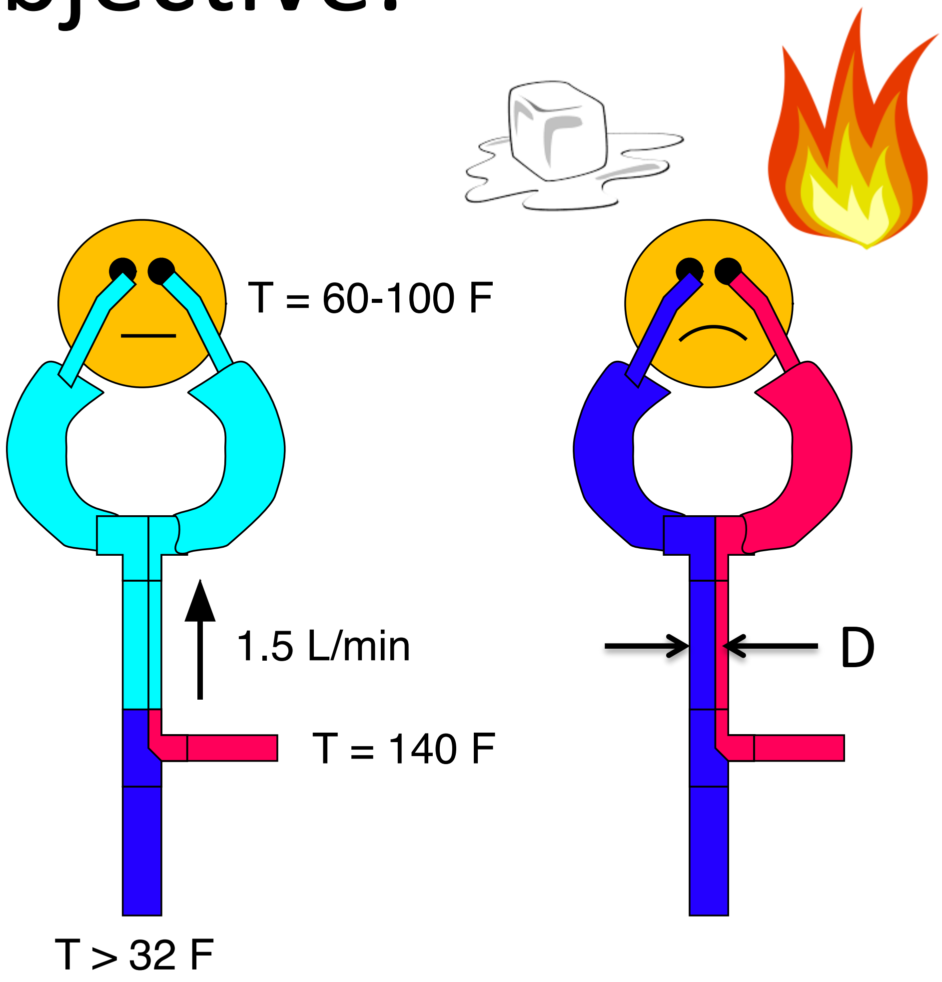
$$f = \begin{cases} 64 / \mathrm{Re}_D & \text{(laminar)} \\ 0.316\,\mathrm{Re}_D^{-1/4} & \text{(turbulent)} \end{cases}$$

Relevance to your lab:

- In your lab, you will observe the transition to turbulence as a function of Reynolds number
- 500 < Re < 20,000
- As part of your analysis, we would like you to plot the calculated pressure drop in pipe vs. average velocity.
  - dimensionless (f vs Re) -> dimensional (P vs V)
- Plot it on a $\log_{10}$ vs $\log_{10}$ plot. Just like Reynolds!

Design Objective:

- Design an eyewash station
- OSHA Compliance ->
  - ANSI Standard Z358.1
- Choose appropriate pipe diameter to induce turbulent mixing
- Make a conservative estimate!
  - Which temperature should you design for?
  - Which Re should you design for?
    (Use YOUR data)
  - Should you choose a pipe diameter bigger or smaller than that?



Lab X6

Measurement of the friction factor

2017 Rev 1

Reynolds Number for flow in a Pipe or tube

The Moody Chart is a general plot of laminar, transition, and turbulent flow

In lab, we will vary the flow rate (velocity) through a Smooth tube.

By observation at each flow rate we will mark it

- Laminar,
- Transition,
- or Turbulent

Calculate the Reynolds number at each observation and plot on the Moody Chart.

Discussion- do observations match plotted position?

This experiment duplicates a classic experiment by Osborne Reynolds in 1883, supplemented by many others.

The methodology is seems straightforward, but requires great care.

Transition to Turbulence