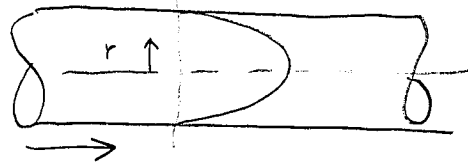


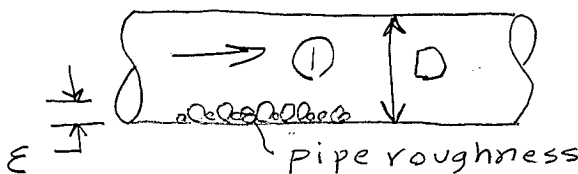
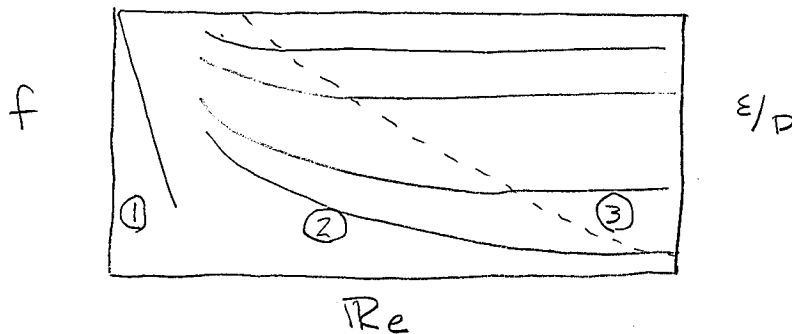
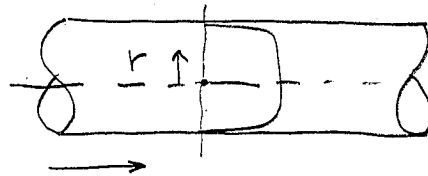
WHAT CAUSES FRICTION LOSS?

1. fluid: ρ, μ
2. flow: V
3. pipe: D, ϵ

Laminar flow:
 $V(r)$ is parabolic
 friction $\propto V^1$

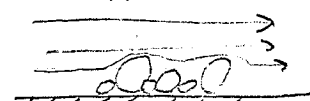


turbulent flow:
 $V(r)$ is logarithmic
 friction $\propto V^2$

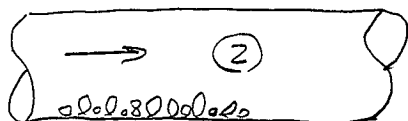


Laminar:
 all roughness in
 laminar sublayer

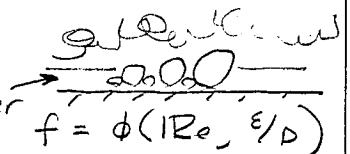
DETAILED LOOK
 AT WALL



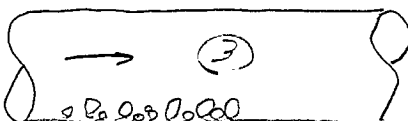
$$f = \phi(Re) \text{ only}$$



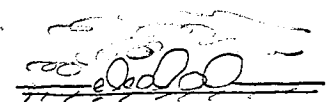
Turbulent:
 part of roughness
 in laminar sublayer



$$f = \phi(Re, \epsilon/D)$$



Wholly Turbulent
 turbulence extends
 very close to wall



$$f = \phi(\frac{\epsilon}{D}) \text{ only}$$