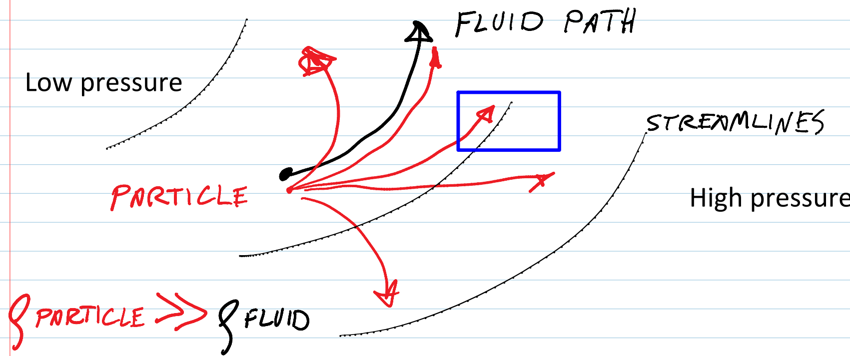
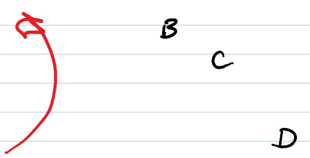
~~Minute paper:~~ Consider a curved streamline. Consider a small particle, much denser than the fluid, BUT small enough that gravity is negligible compared to forces of the fluid on the particle. (diameter ~ 100 µm)
What will the particle path look like compared to the fluid path? Sketch.

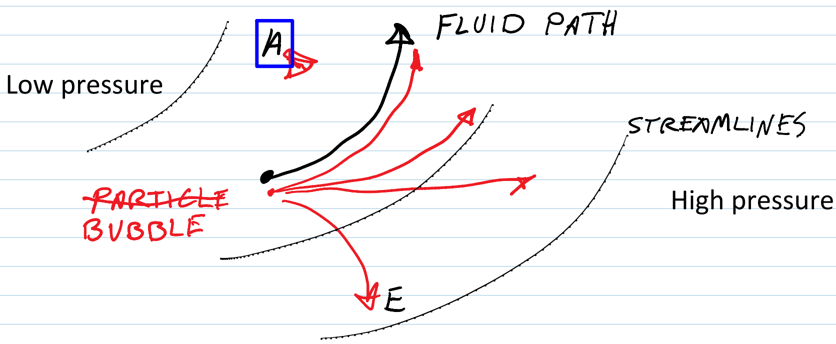


So, Pressure gradient makes streamlines bend.
FORCE acting on the solid particle = Force acting on nearby fluid particles.
F = ma
Mass of solid particle is larger, so acceleration (towards the center of curvature) is smaller. Won't curve as tightly.

What if we have a bubble instead of a solid particle?

$\rho_{BUBBLE} \ll \rho_{FLUID}$





Rules of thumb:

- In water, particles of 100 µm diameter or less, any density, will track most flows.
- In air, particles of 1 µm diameter or less, any density, will track most flows.

Similar considerations to dyes:
1)Want particles to NOT disturb flow
2)Want particles to show up - HIGH VISIBILITY
3)Particles must track with the flow DONE

1)Want particles to NOT disturb flow

- As with dyes, minimize injection differential velocity; inject at local flow speed.
- Want particles to not introduce new forces. Avoid:
  - soluble particles
  - surface tension
  - chemical reactions
  - significant change of density
  - particle-particle interaction
    - Number density of particles = # of particles / unit volume. (Contrast to mass/volume of solid alone). Keep low enough to avoid interactions.
    - Particle-particle interaction (collisions, drag) lead to non-Newtonian effects. Slurries, oobleck, blood, shampoo, silly putty, other polymers. Gets into 'complex fluid' categories. Interesting field.

2) High visibility

Particles only scatter light. Interaction depends on size (d) compared to λ.

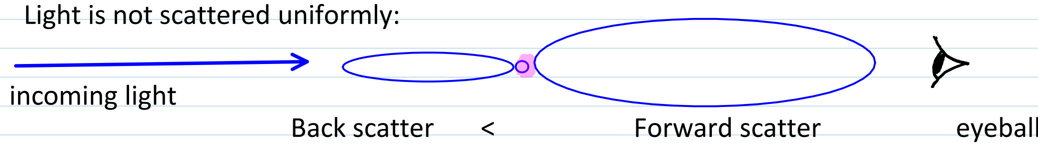
d ~O(λ) : Mie scattering regime.

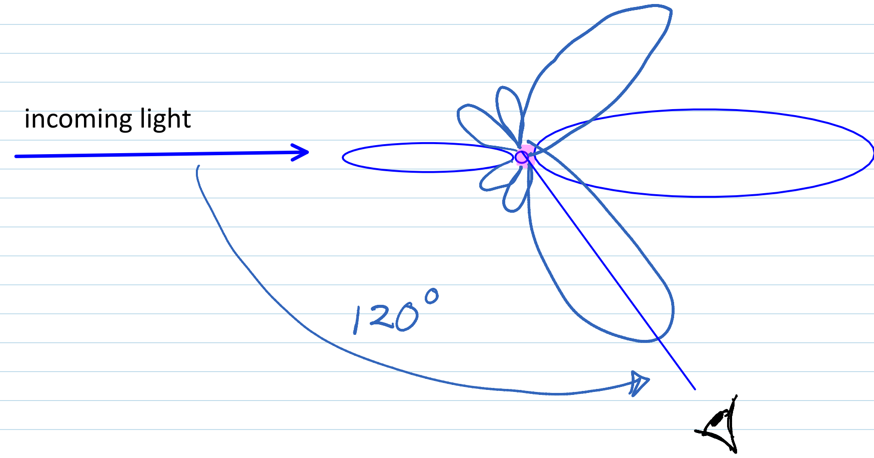
e.g. visible light =0.7 - 0.4µm, so diameters of 1 µm to 0.1µm (100 nm, 1000 A).

- Scattering efficiency drops as particles get smaller. Better tracking, but less light.
- Independent of wavelength; no colors from particles this small.
- Particles large enough to have color are too big to track well.

"NASA wing tip vortex. Information for ID # EL-1996-00130," n.d., http://lisar.larc.nasa.gov/UTILS/info.cgi?id=EL-1996-00130.

Light is not scattered uniformly:





Often a strong lobe at 120 degrees to incoming light.

Smaller particles, d << λ,
Rayleigh scattering regime. Elastic collision of photons with particles. No energy exchange.
Blue sky is Rayleigh scattering; sunlight scattered by molecules of air, preferentially blue. Longer wavelengths are too long to interact much; are only seen at sunset due to long passage through atmosphere, and when scattered by larger molecules of pollutants or dust.