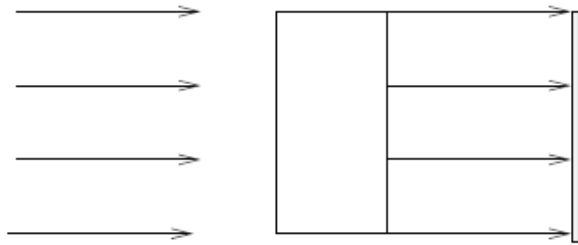
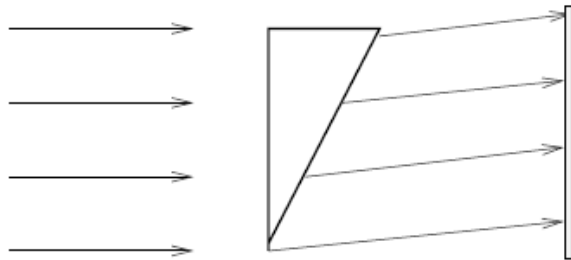


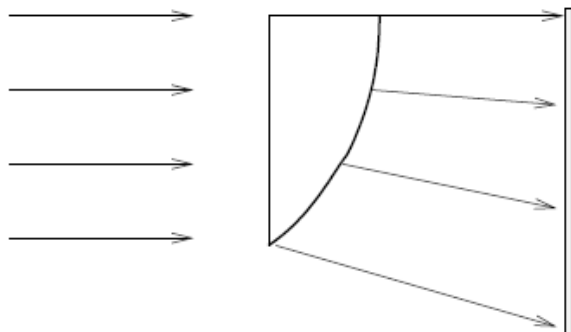
Deflection of light rays



Constant density



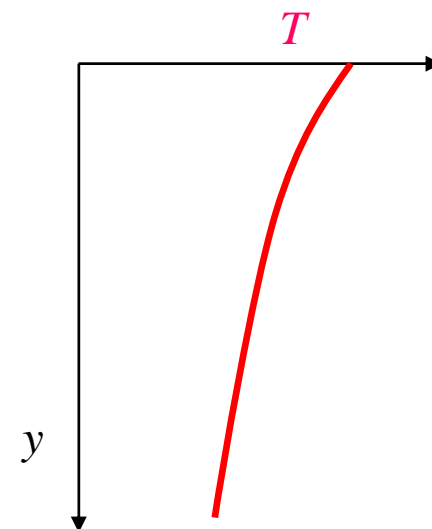
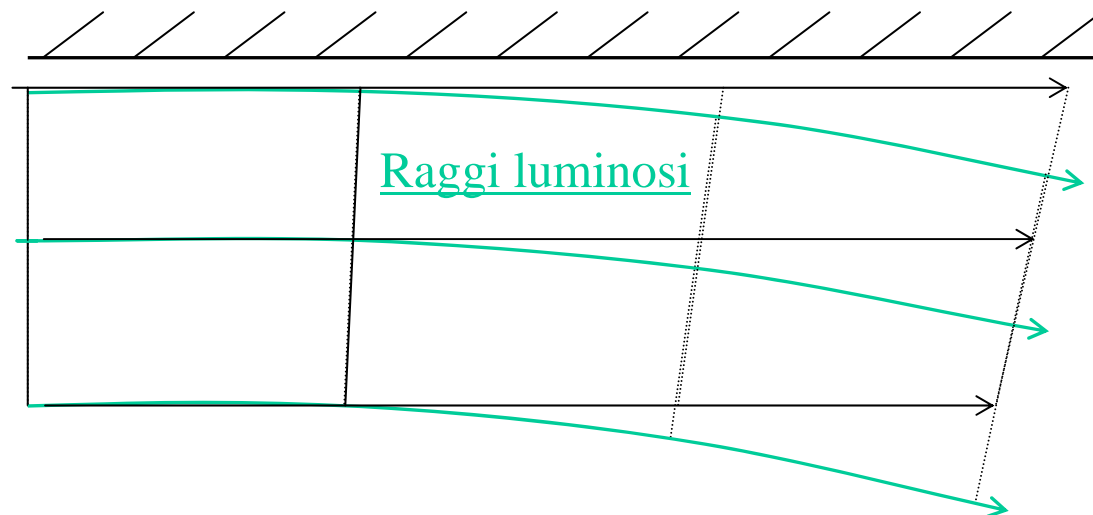
Constant density gradient



Constant second derivative

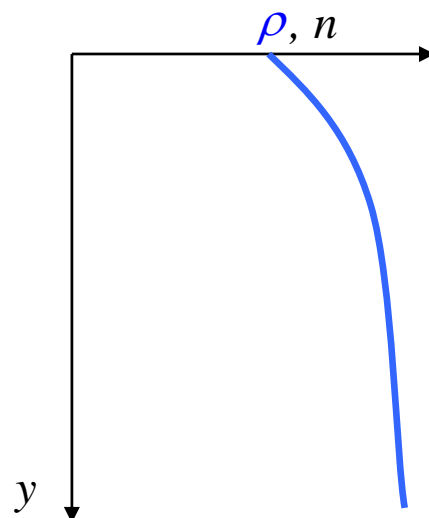
see Merzkirch [1974]

Gladstone-Dale Law: $n - 1 = K \rho$

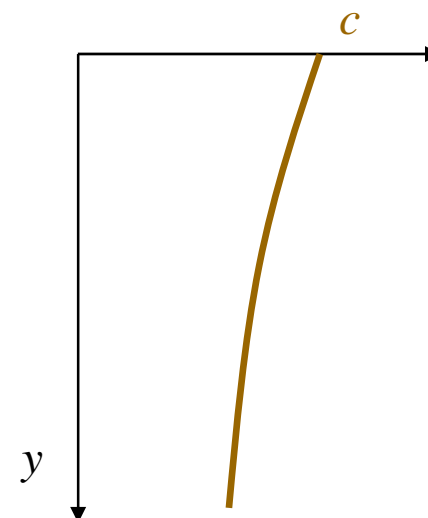


$$\rho = p/RT$$

$$n = 1 + K \rho$$

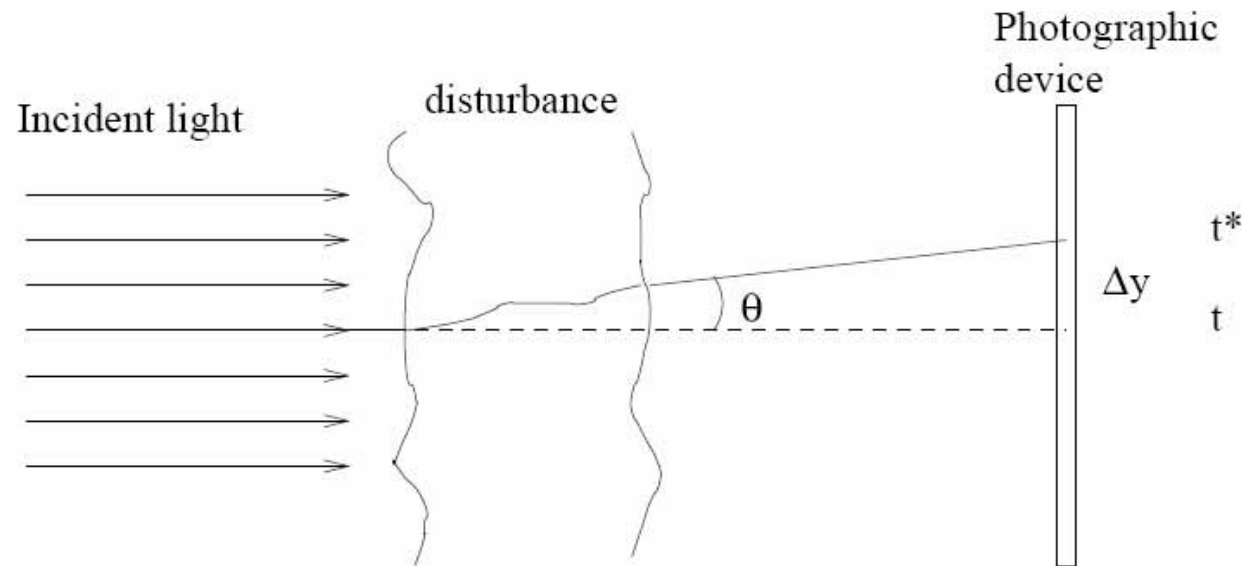


$$c = c_o/n$$



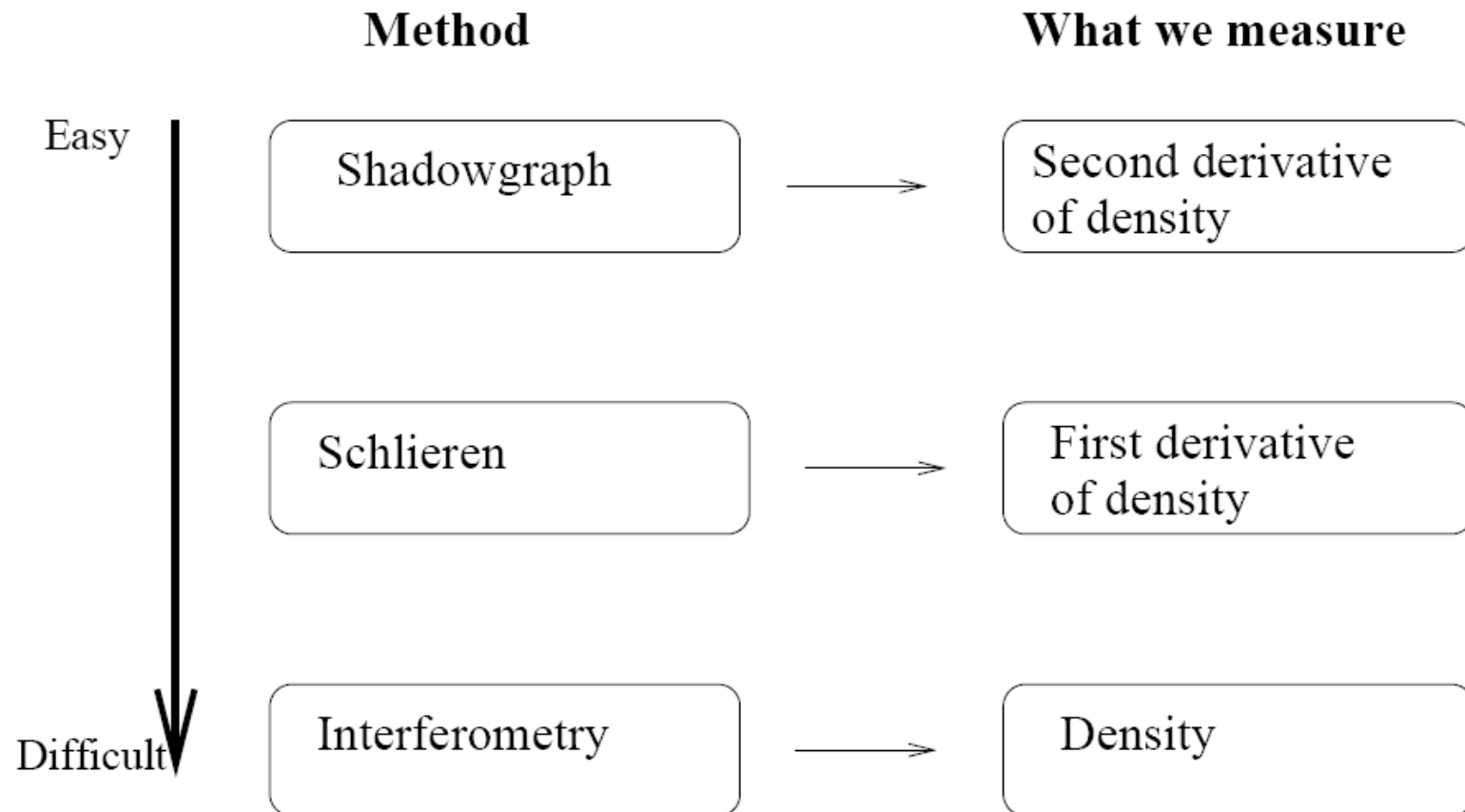
What do we see?

Looking through a fluid



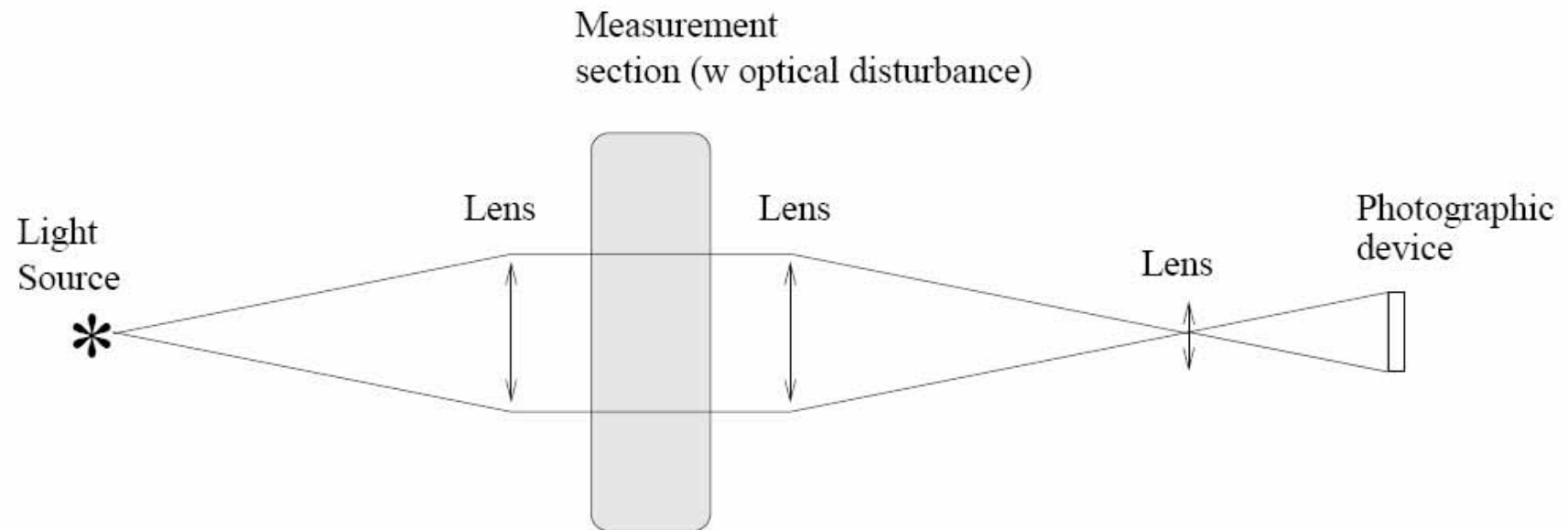
- Shadowgraph - measure Δy
- Schlieren - measure θ
- Mach-Zendner Interferometer - measure phase-shift
$$\Delta\omega = 2\pi(t^{-1} - t^{*-1})$$

See the light



Shadowgraph

- Pionered by Dvorak (1880)



Shadowgraph

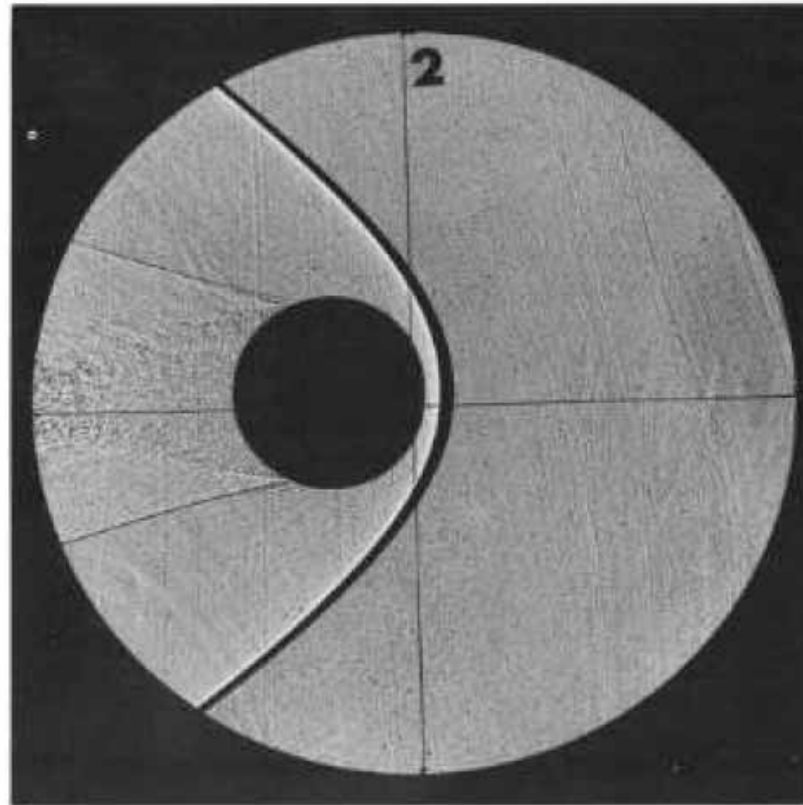


Fig. 3.10 Shadowgraph of a sphere flying at a Mach number of $M = 1.7$. (From Stalp, 1968.)

Picture copied from Merzkirch (1974)

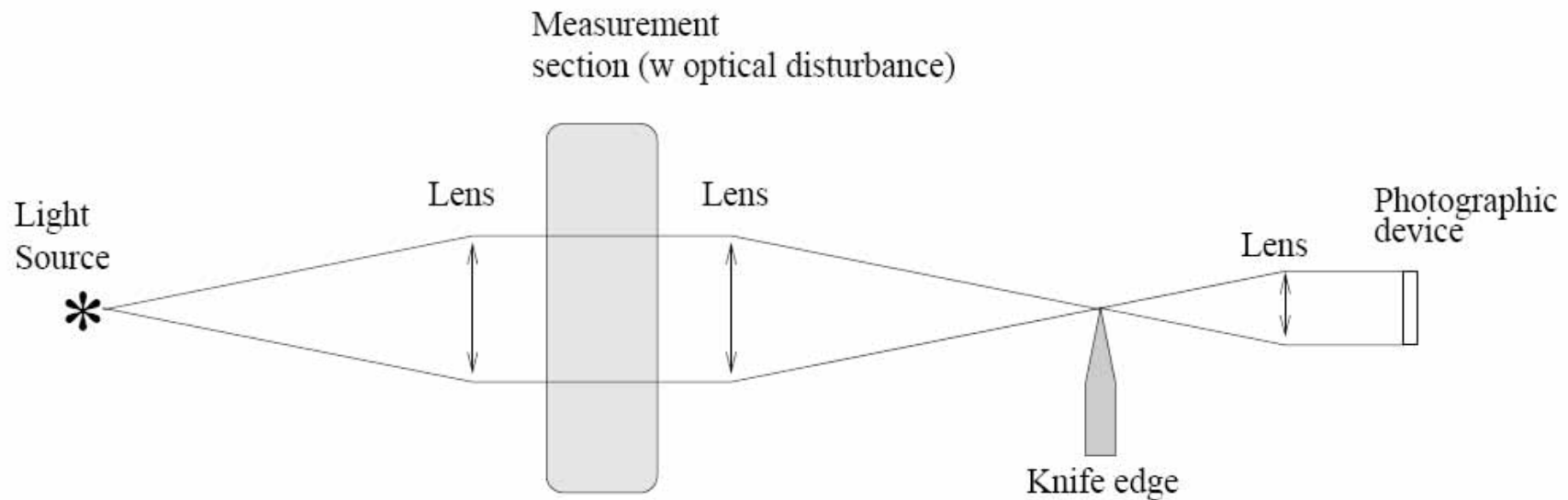
Schlieren

- Attributed to Focault (1859) and Toepler (1864) (dep. on national preference)
- Used by Focault to check quality of lenses and mirrors
- Elaborated by Toepler

Now often referred to as the “Toepler method”

Schlieren

- Idea: Introduce knife edge at focal point
 - light bent down is removed → darker-spots
 - light bent up is kept → brighter-spots
- Direction of density gradient known



Schlieren - example

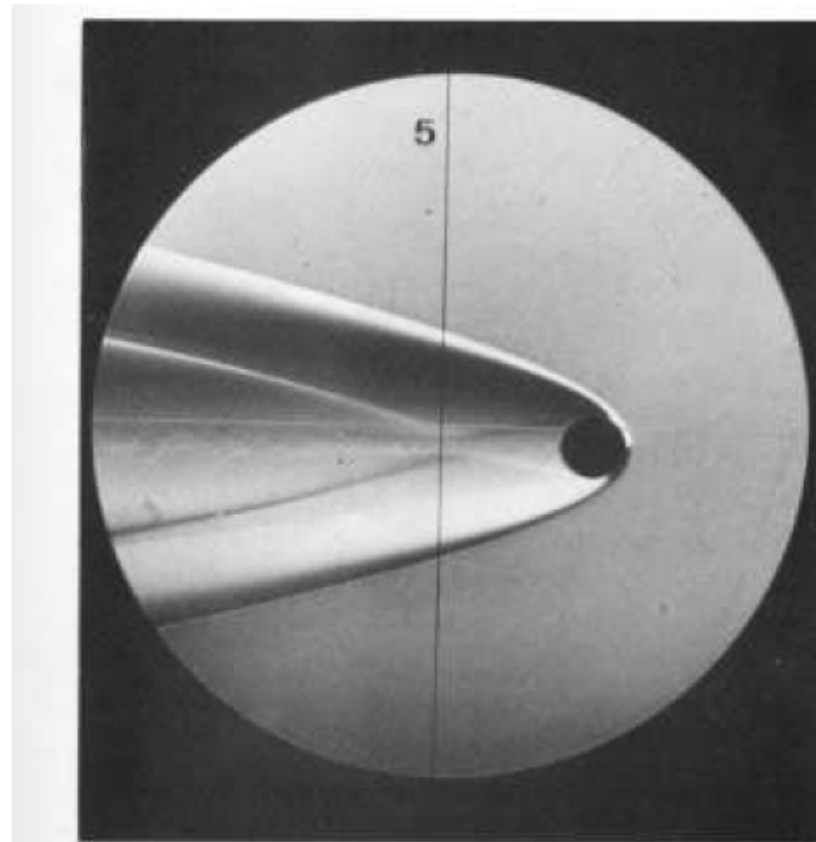


Fig. 3.18 Schlieren photograph of the flow field around a sphere flying at hypersonic speed. (From Stulp and Merzkirch, Ernst-Mach-Institut, Freiburg, Germany.)