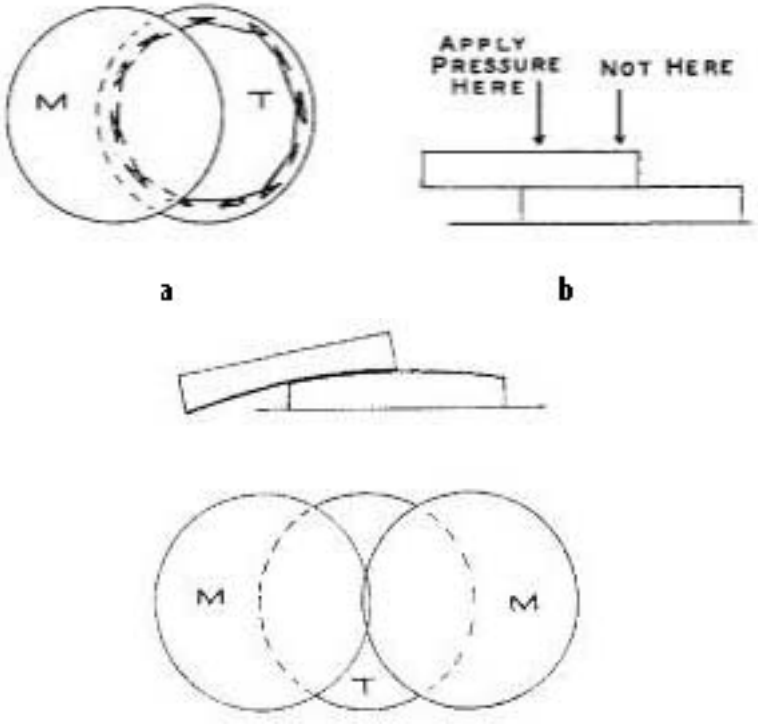
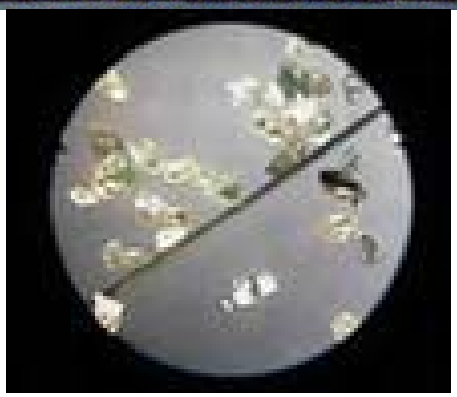
Lens & Mirror Making

- Best lenses and mirrors are both made by grinding the surface
- Start with a mirror or lens blank
- For mirrors only surface needs to be good
- Typical mirror want pyrex (eg BK7)
- Then need a tool blank – poorer glass & softer glass
- Place mirror on top tool
- Now add grinding compound (grit) between tool & mirror
- Grinding – moving the mirror over the tool with grit between)
- Grinding compound will make tool convex, mirror concave



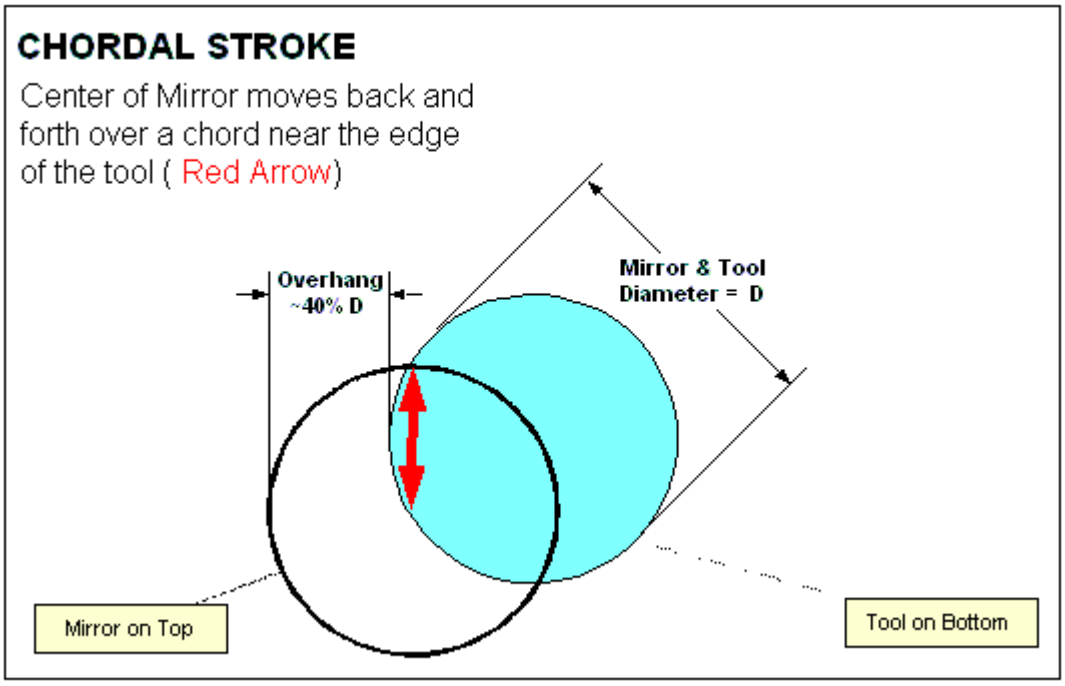
Grinding Compounds

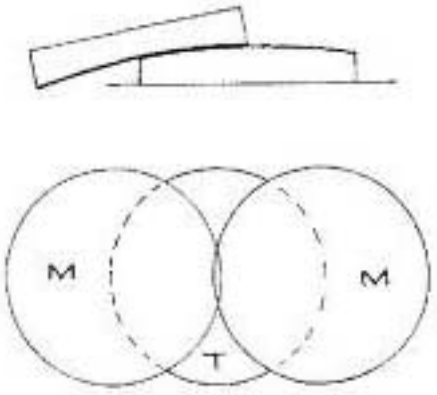
- Grinding compound is material much stronger than glass
- Made of fine powders, grit, in water solution
- Typical materials silicon carbide, aluminum oxide (sapphire)
- Start with largest grit
- Size is give as number of holes per 1 inch
- 60 grit ~ 254 microns
- Put grit in water to create grinding solution (paste)



Grinding Motion

- Move mirror back and forth over tool & grinding compound
- After number of strokes rotate mirror, tool in opposite direction
- Change position of stroke alternatively
- Eventually move fully around the mirror
- Grit removes material from both
- But tool edges wear down, while mirror center carved out

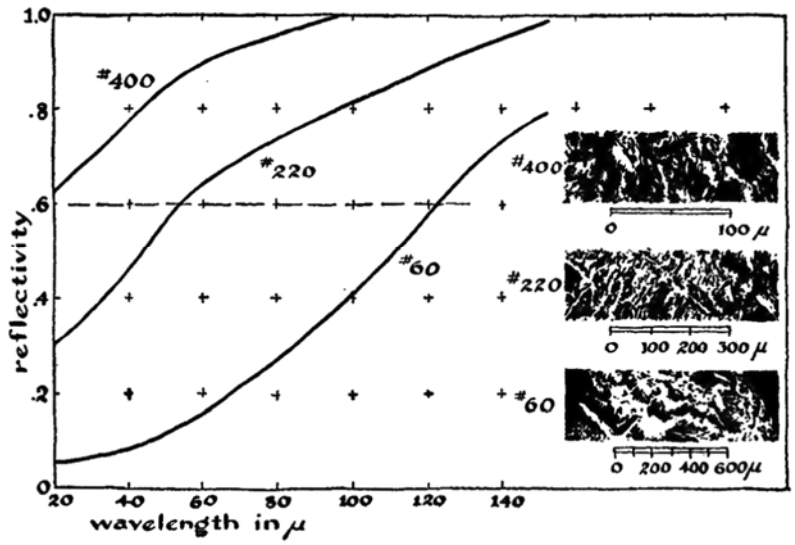




Progressive Correction

- 60 or 80 grit used to create the rough surface.
- Use simple depth measurement to roughly check
- Measurement or templet
- But rough grit leaves rough frosted surface
- Need to create smoother surface
- Now switch to finer grit 60 to 80 to 120 … 1000 grit
- 60 grit creates ~ 200 um holes – need to get to λ/4 at least
- Each grit removes damage of previous level

FIG. 13-3 Dependence of specular reflectivity on roughness.

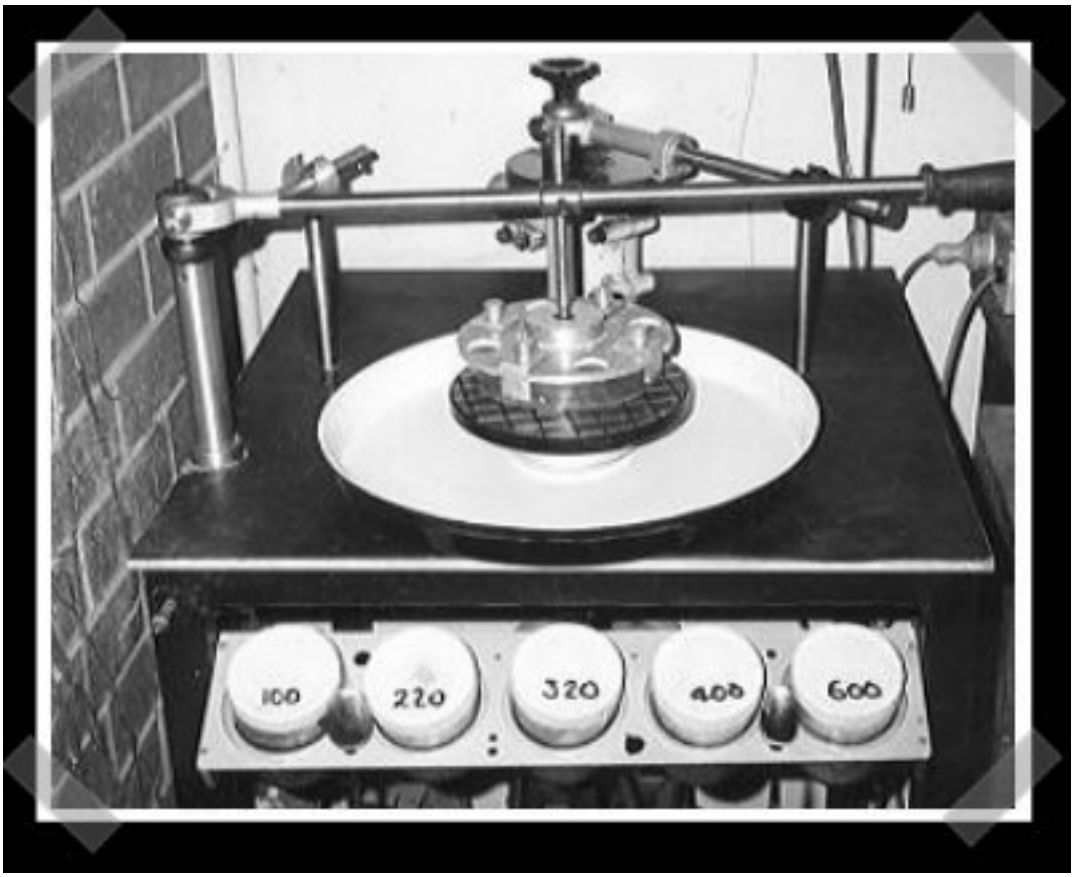


Polishing

- Need to get to λ/4 at least, λ/8 typical
- Now cover tool with a softer surface
- Use a pitch lap (or similar)
- Use a soft material, cast on surface, & cut groves in it
- Classic is pitch (from trees) heated and cast on surface.
- Then heat and let take shape of mirror
- Now apply a polishing compound – jeweller's rough is classic
- Polish until surface is mirror like & transparent

Grinding Machines

- Hand grinding takes several days
- Grinding machines designed to create exact same pattern
- Can adjust stroke, positions etc – auto rotates mirror and tool
- Simple machines cost few hundred



Figuring & Testing: Foucault Knife Edge test

- When mirror is near finished can start testing for shape (figuring)
- Simple test – wet mirror and see where it focuses light
- Gives rough focal length
- Now must tests to get the exact shape – parabolic etc.
- Most common Foucault Knife Edge test
- Place mirror on stand
- At focus place a pin hole light source (often laser now)
- Observe with knife edge (razor edge) to cut the beam

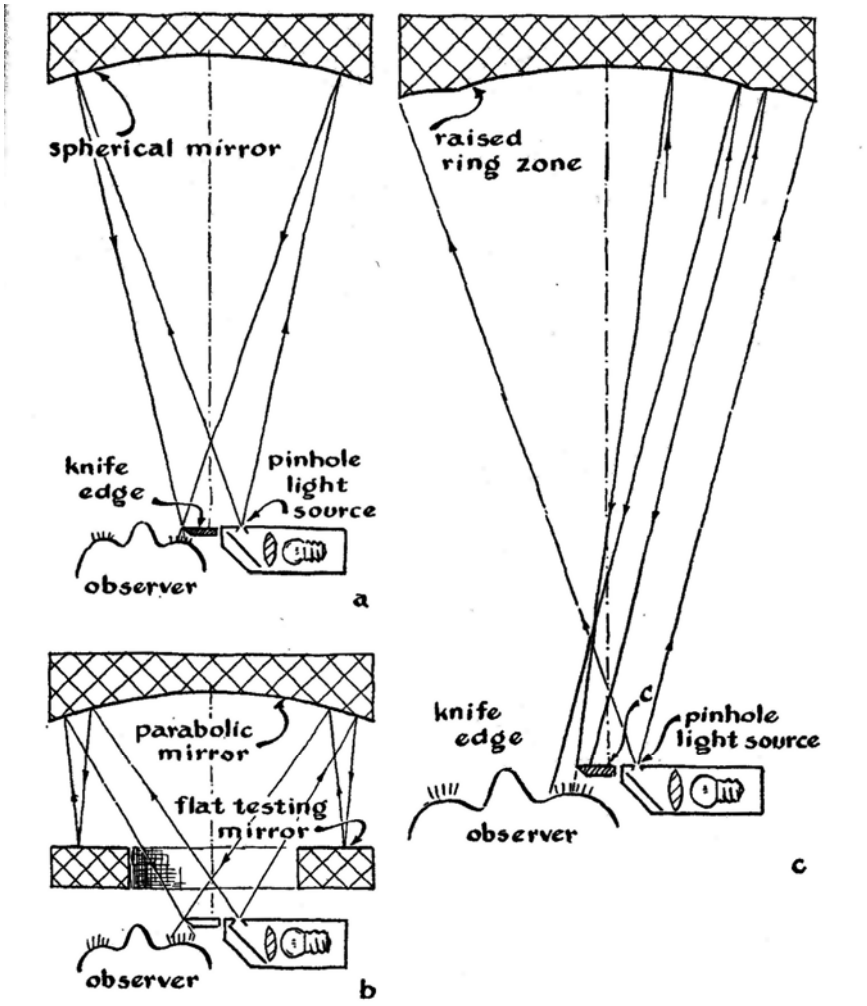
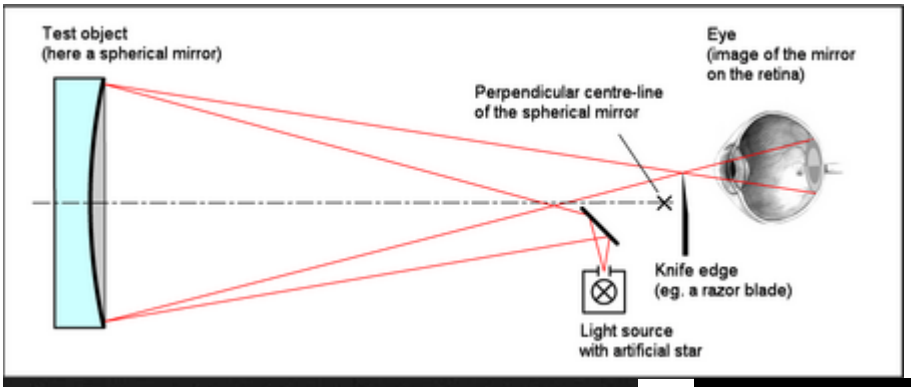
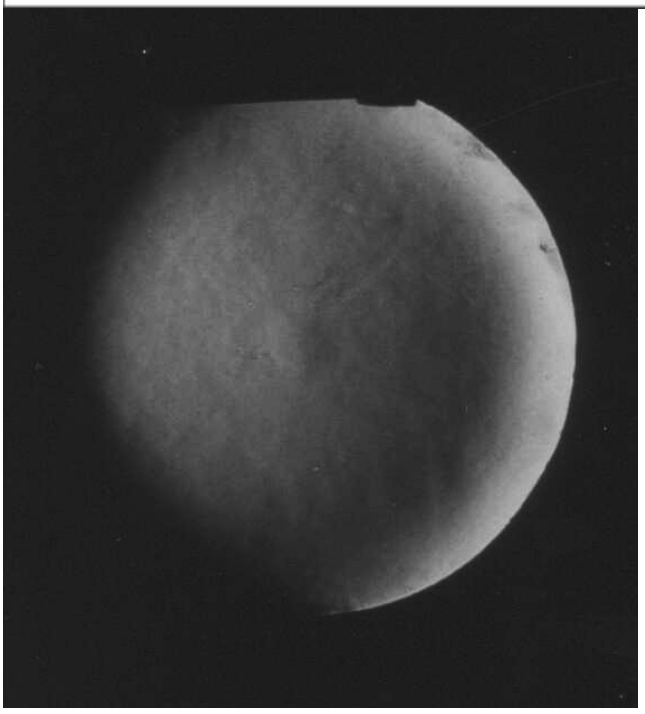


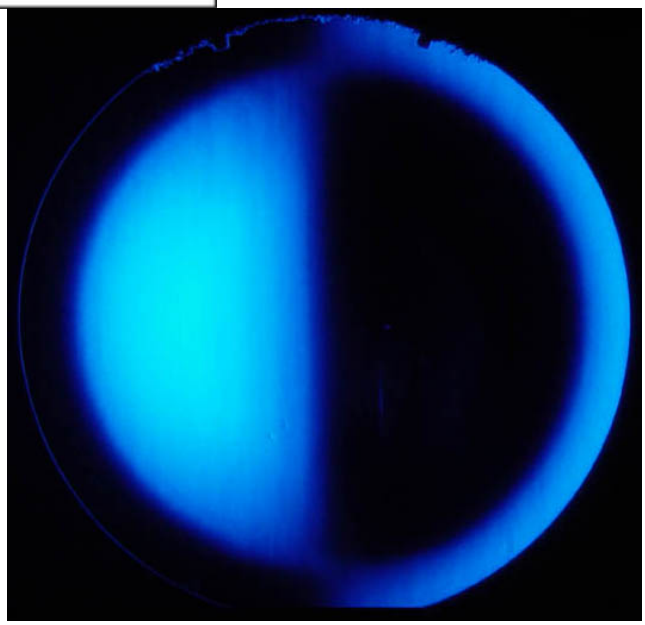
FIG. 13-14 Foucault test of spherical mirror at its center of curvature (a); test of parabolic mirror with auxiliary testing flat (b); test of mirror with symmetrical, raised, intermediate error zone (c).

Foucault Knife Edge test

- Knife edge test shows shape of surface
- Shows up any defects – want a smooth surface
- Shape determination harder

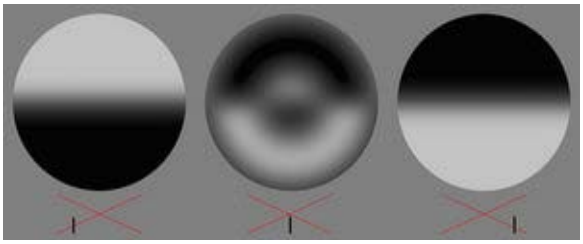


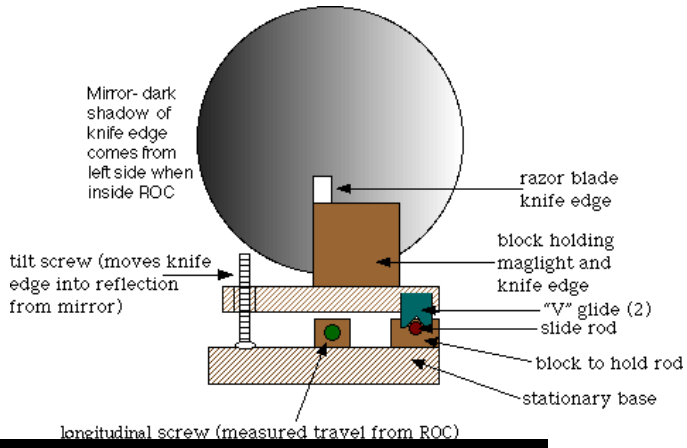


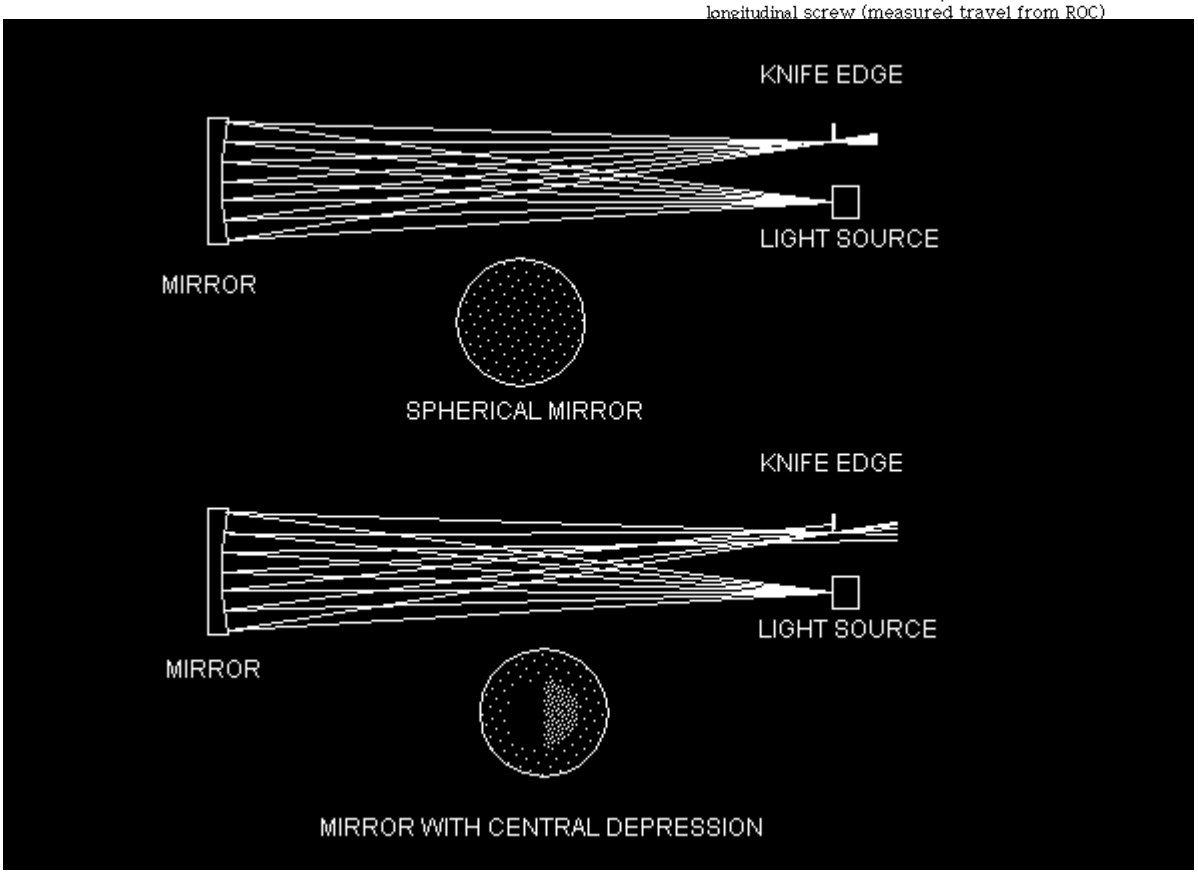


Foucault Knife Edge Shapes

- Need to get knife edge at focus point to get right image
- Shape of pattern tells us about surface
- Flat surface spherical mirror

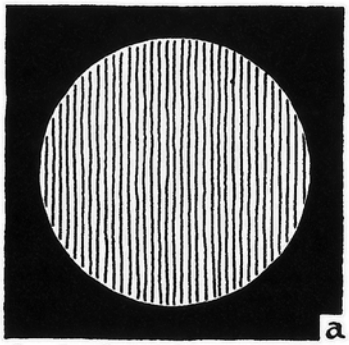




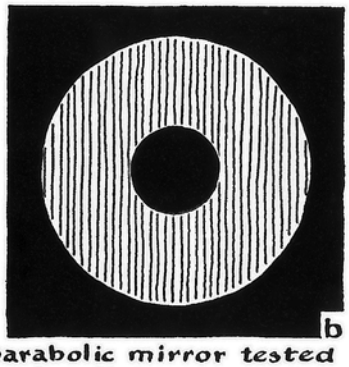


Foucault Knife Edge Shapes Figuring

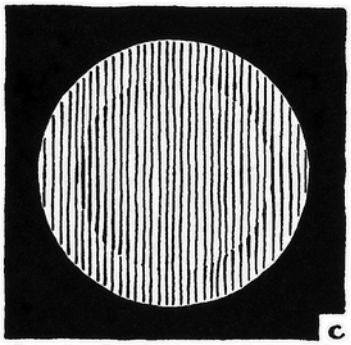
Foucault you just seeing shape
Parabolic want a slight doughnut shape
Test flats against known spherical shape



spherical mirror tested at center of curvature

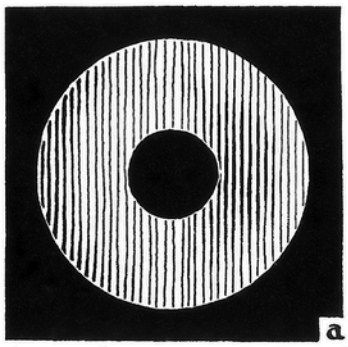


parabolic mirror tested with a flat testing mirror

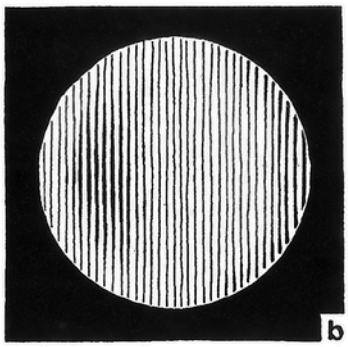


spherical mirror with raised annular ridge as tested at center of curvature

FIG. 13-15 Appearance of mirrors under the Foucault test of Fig. 13–14.



spherical mirror tested with a flat testing mirror

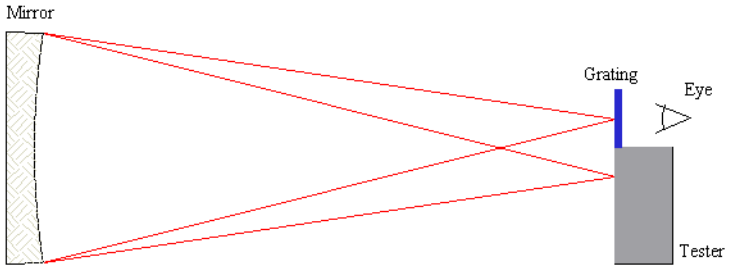


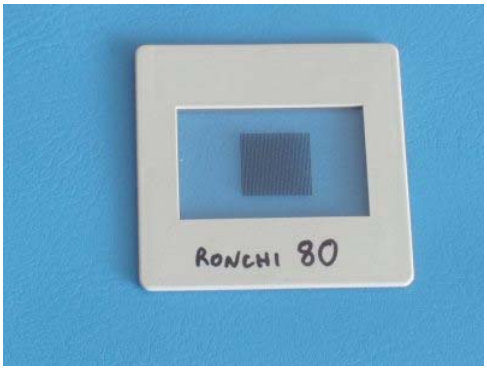
parabolic mirror tested at mean center of curvature

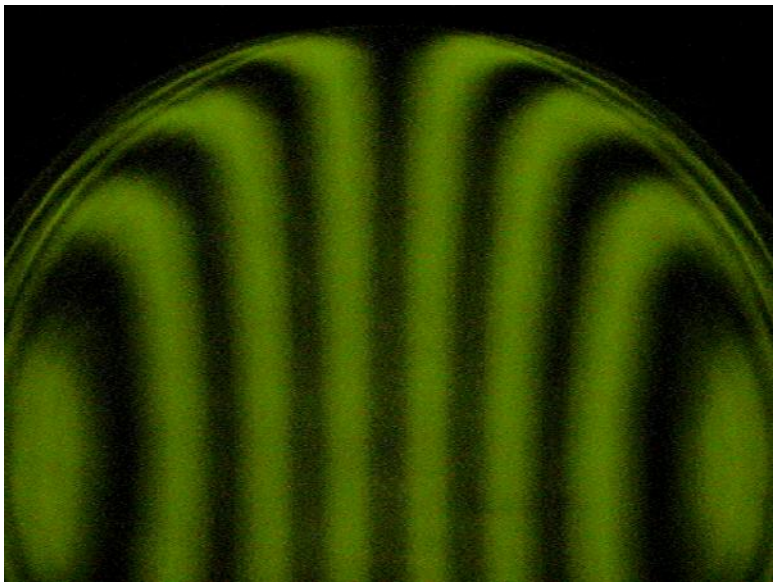
FIG. 13-16 Appearance of mirrors under the Foucault test of Fig. 13–14.

Ronchi Testing

- Ronchi test – observe mirror with a “Ronchi” grating
- Wildly spaced parallel lines
- Creates parallel lines on mirror
- Where lines bend can see defects







Ronchi Testing Patterns

- Watch the shape of the lines
- Straight lines – spherical
- Slight inward curve parabolic
- Bend outward Oblate spheroid
- Bend at edge – turned down edge

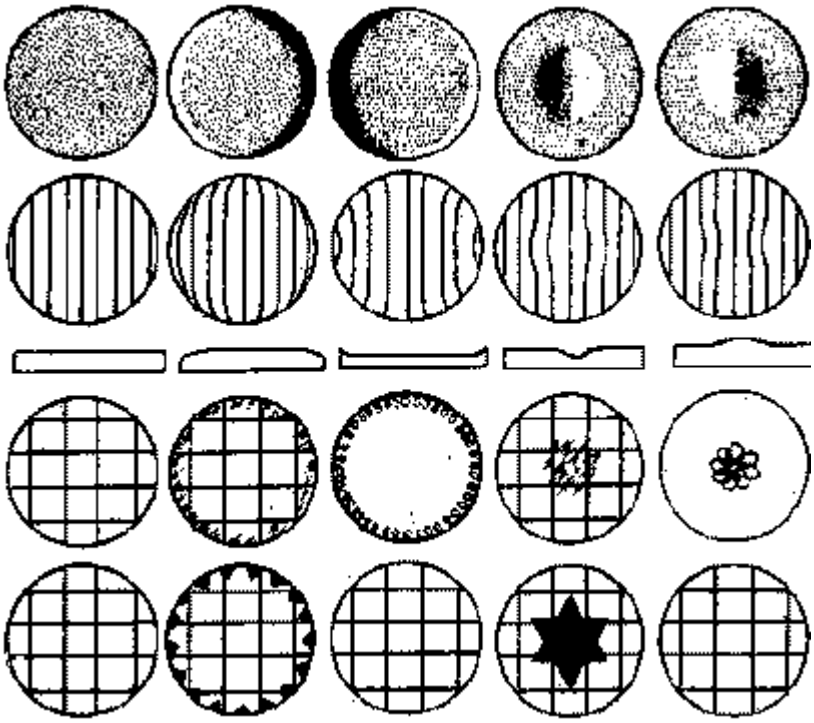
Spherical mirror

Parabolic

Oblate spheroid

Foucault and Ronchi Testing Patterns

- Foucault and Ronchi show the shape of the surface
- Now use different strokes and lap shapes to correct this
- Test and reshape then test again



Foucault

Ronchi

Surface

Laps to correct

Twyman-Green Interferometer

- Use Interferometer to view surface
- Add lenses to turn mirror light into parallel beam
- Easy to detect defects – problems in surface

Figure 15.6
Twyman-Green Interferometer

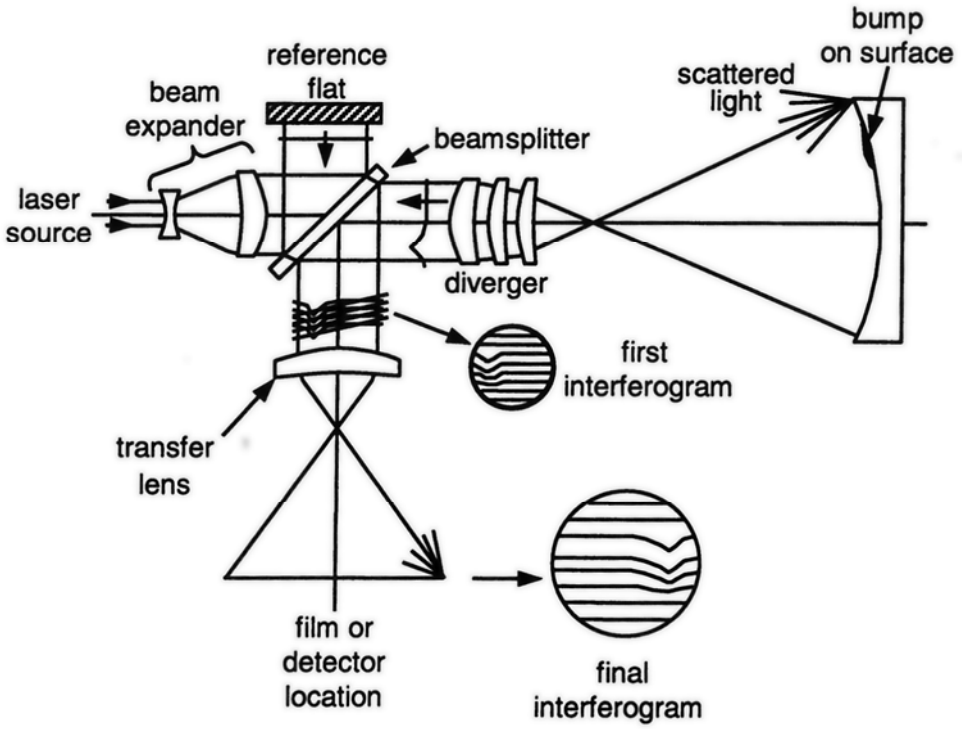


Figure 15.9
Typical Interferograms of Nominally Flat Mirrors

interferograms of thin aluminum mirror
(both interferorgrams are of same mirror)

interferogram of thin aluminum mirror with astigmatism or saddle

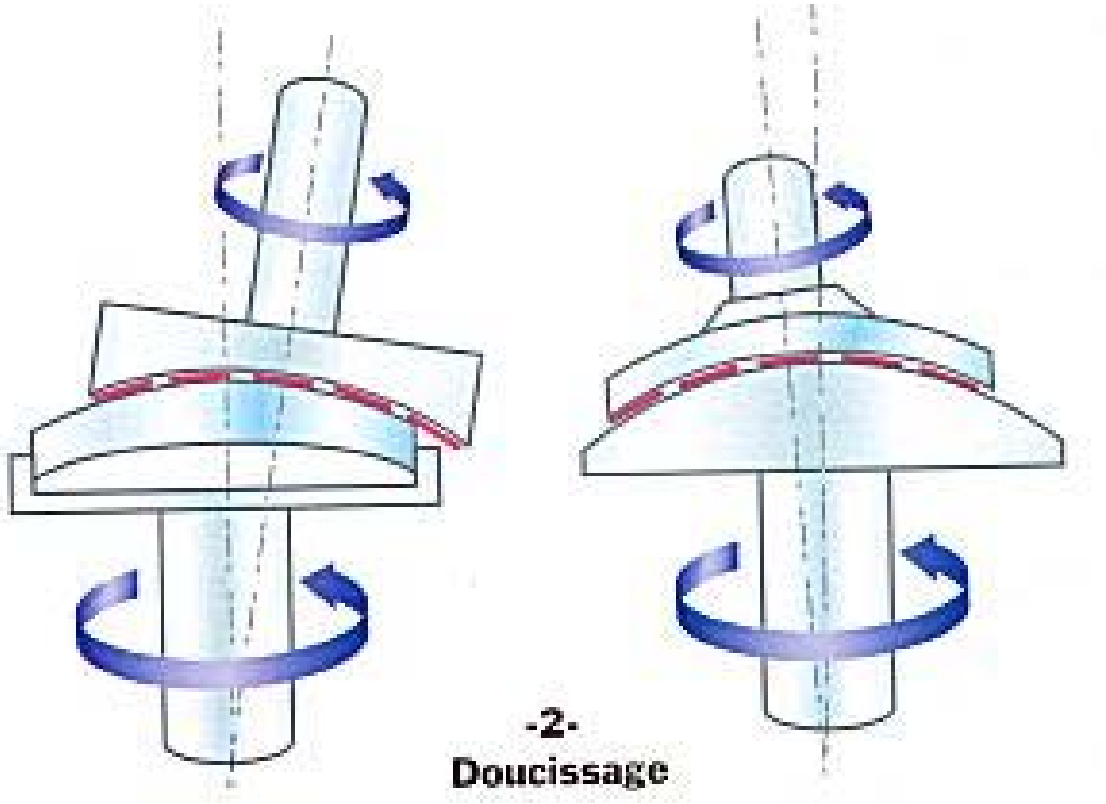
interferogram of thin beryllium mirror

Lens Making

- Lens making same process
- But usually make many copies of same lens
- Much larger shaping of glass
- Use a grinding tool to make rough shape

Lens Polishing

- Now use shaped tool for each lens
- Finer grits and polishing done similar but with a master for lens
- Auto grinders shaper, rotate lens and tool, and polish
- Eyeglass companies use similar system



Casting Lenses

- Lens has such large change can make plastic cast lenses
- Lower quality, but much cheaper
- Used in cheap cameras
- Use an injection molding machine
- Start with raw plastic beads
- Grind and melt them
- Inject into mold
- Mold opens after cooling
- Can get nearly $\lambda/4$
- Create both lens and optical fixture eg for DVD lens system