the specimen. However, note that many manufacturers' alignment procedures are performed in image mode where these distortions can occur.

The presence of aberrations in the probe-forming optics adds more complications to the Ronchigram. Spherical aberration causes high-angle rays to be brought to a premature focus higher up the column (Fig 4a). When the probe-forming lens is underfocused, the Ronchigram has two distinct areas: a central region where the shadow image is reversed, and an outer region where the shadow image is not reversed because adjacent rays in this region are crossing each other above the specimen plane (Fig 4b). The presence of any other misalignment or astigmatism in the probe-forming optics will further drastically distort the symmetry of the pattern, as we see in the experimental data in Fig 3: this is why the Ronchigram is such a good tool for lining up the STEM mode column. If it is possible to adjust the electron optics so that the Ronchigram is completely flat (the same intensity everywhere), then this implies that every electron has passed through one point in the specimen: in other words, the STEM probe is perfectly focused. Aberrations prevent us from achieving this, but if we get close to a 'flat' Ronchigram (i.e. with as little structure as possible) then the STEM performance will be very good indeed.

ALIGNMENT PROCEDURES USING THE RONCHIGRAM

It must be emphasised that the spatial resolution of a STEM probe is completely unaffected by anything that happens to the electron optics below the specimen, although the projector system does determine the camera length of the STEM detector arrangement. In other words, our task is to get the gun, the condenser, the condenser aperture, the condenser stigmators and the objective pre-field aligned with each other. Figure 5 illustrates some common forms of misalignment. Different manufacturers have different lens configurations, the main variable being the height of the mini-lens (either condenser or objective) between C2 (or the lowest condenser lens) and the objective pre-field, and the number of beam crossovers in this region. However, whatever the exact configuration, the only thing to remember is that in a perfectly aligned microscope, all image movement in the Ronchigram from an amorphous or non-crystalline material is concentric around a single axis (the optic axis) as a function of any lens used to form the probe.

Start by aligning according to the manufacturer's procedures for both TEM and STEM. Load an easy test specimen like gold particles evaporated on a thin carbon film. Select the largest condenser aperture in TEM mode and align it in the usual way. Obtain the Ronchigram in 'STEM' and 'diffraction mode': the Ronchigram should just appear on the phosphor screen. If it doesn't, go down in camera length until you see something. Check the probe is not scanning and that the STEM is at its highest magnification. Wobble the objective lens (i.e. the current rotation centre), adjusting the beam tilt until the centre of magnification is at the centre of the condenser aperture: this corrects the errors of the type shown in Fig 5a. Coarsely adjust the condenser stigmators. Astigmatism in the Ronchigram appears as streaking across the centre of the pattern (Fig 3c). Adjust the focus of the objective until it lies between the two orthogonal extremes of the streaking, and then adjust the stigmators, i.e. the condenser stigmators, to get a smooth, flat intensity region at the centre of the Ronchigram, as much like Fig 3d as possible. Remember that in contrast to conventional imaging, this flat featureless condition is when the Ronchigram is 'in focus' in the sense that the probe is as small as possible in the specimen plane (think of Fig 2d).

Starting from this coarse in-focus Ronchigram, try altering C2. This may be fixed by the computer control software, but there is usually a way to unlock it: e.g. on the Philips CM series by going to 'μdiff' mode, on the JEOL JEM

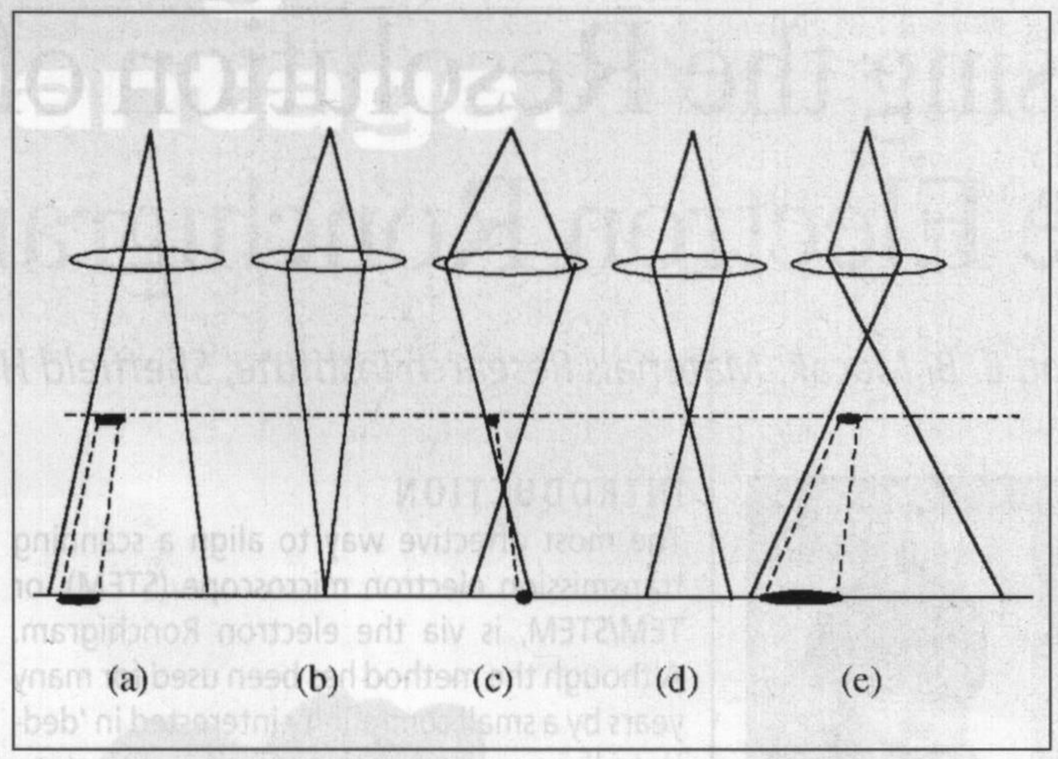

Figure 2:
How a probe-forming lens changes what is seen in the Ronchigram. The dotted horizontal line is the plane of the specimen, the solid horizontal line the plane of the detector (ideally, an infinite distance from the specimen). The lens strength increases from left to right. A feature on the specimen casts a shadow onto the detector (the Ronchigram is sometimes called a shadow image). Note the reversal of the shadow image in (c), that the probe is imaged in (b), that (a) and (e) give similar images, and that the STEM probe is focused on the specimen in (d).

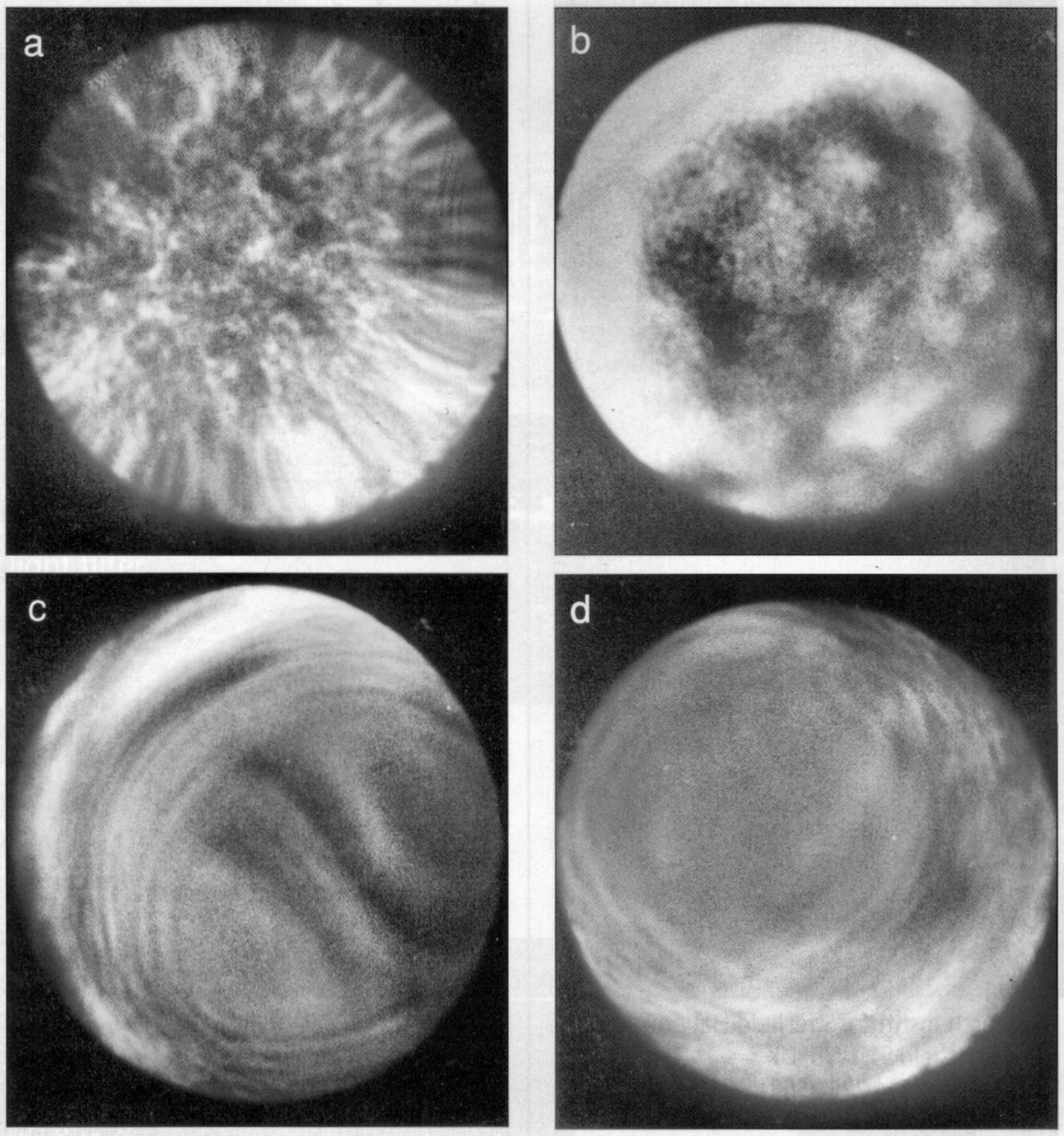

Figure 3:
Experimental Ronchigram obtained in a CM20 with a tungsten filament. The specimen is gold islands on thin amorphous carbon. (a) Underfocused. The central region is reversed (see Fig 2c), the streaking in the outer region is called the ring of infinite radial magnification. (b) Overfocused (see Fig 2e). (c) Severe astigmatism in the condenser at focus. (d) In focus (see Fig 2d): the large flat area of intensity arises because all central beams pass through the same point of the specimen.