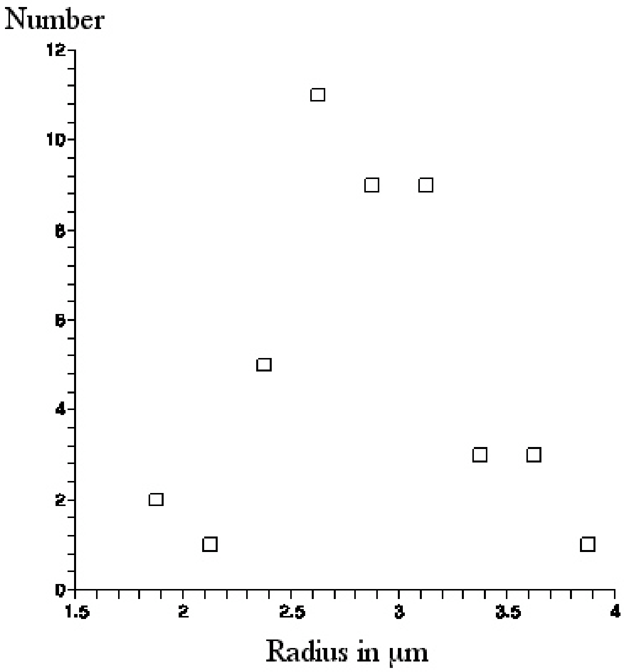

FIG. 17: Number of amyloplasts in a .25 μm radius bin vs amyloplast radius (= half amyloplast length).

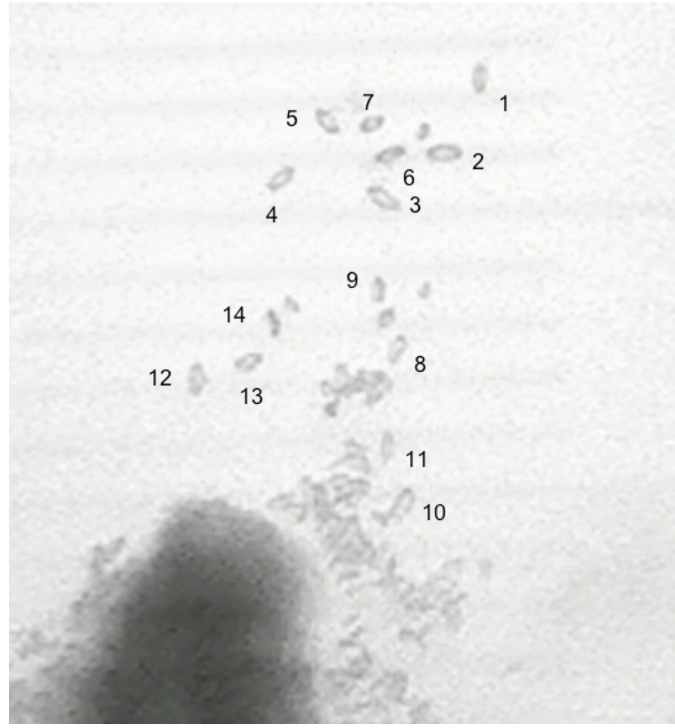

FIG. 18: Amyloplasts photographed with the ball lens microscope. The superimposed scale marks (the faint horizontal lines) are 10μm apart.

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VI. THEORY

The appendices contain seven mathematical tutorials.

Appendix A contains a derivation due to Langevin, of the well known expression, given first by Einstein[76], for the mean-square displacement of an object undergoing Brownian motion[77]. The method is easily applied to give the mean-square angular displacement of an object undergoing Brownian rotation.

These expressions depend upon the viscous force or viscous torque on the object. Such fluid flow analysis is not treated in places which treat the material of Appendix A. The results for a sphere are derived in Appendix B[78]. For an ellipsoid, results are just cited[79].

Appendix C presents a derivation of geometrical optics starting from the wave equation. The discussion here, utilizing the WKB approximation in 3 dimensions, does not seem to be given elsewhere, although the result (the eikonal approximation of geometrical optics) is well known. Appendix D, a digression, applies this result to mirrors and lenses. It is emphasized, because of the approximate solution's abrupt discontinuities at the boundaries of mirrors and lenses, that it must be modified in order to better satisfy the wave equation.

Appendix E contains the modification, obtaining from Green's theorem, in a standard way, the Huyghens-Fresnel-Kirchhoff expression for a diffracted wave emanating a lens[80]. Then, in Appendix F, this theory is used to discuss lens imaging of a point source. Usually, books on optics discuss the diffraction of a lens (due to its limited aperture) and the spherical aberration of a lens (due to the image made by rays at the rim of the lens having a different focal plane than the image made by near-axial rays) separately. Then, no expression is given for their combined intensity. Here, diffraction and spherical aberration receive a unified treatment. As a concrete example, the theory is applied to what is seen through a 1mm diameter ball lens used as a microscope. The optimum choice for the exit pupil for such a lens, to minimize spherical aberration, is discussed.

Appendix G applies these results for a point source to an extended light source, an illuminated hole of radius a. The apparent radius of the image is discussed, for small and large a. As discussed in section III H, results are obtained which illuminate (sic) Brown's observations of "molecular" size,