# The S.E.M.: Seeing a New World

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*They say to me in their awakening,*
*"You and the world you live in are but a grain of sand*
*Upon the infinite shore of an infinite sea."*

*And in my dream I say to them,*
*"I am the infinite sea, and all worlds*
*are but grains of sand upon MY shore."*
—Kahlil Gibran (1883-1931)

JUST AS AN APHORISM can bring new insights, the scanning electron microscope can open new perspectives on the microscopic world.

The SEM (as it's abbreviated) magnifies the surface features of specimens. It's a kind of handlens, if you will, but a magnifier extraordinaire! The machine offers substantial improvements over the light microscope in three important areas: magnification, depth of field, and resolution — which means it depicts the microscopic world as it's never before been seen.

Consider a single fleck of sand, picked by happenstance from a shore of countless grains, placed in the SEM, and magnified thousands of times. It is seen as a gigantic boulder, a veritable asteroid from microspace. Zooming in on its every crag and cranny, you cannot help but ponder the infinitude of a world to which we have previously been blind.

Why have we been blind to this realm — or rather, how is it that we can now see it? The answer is that we're seeing it in an unconventional way: not with light, but with electrons.

## "Seeing" with Electrons

The first step in electron microscopy is to generate electrons, by running current through a tungsten filament, causing electrons to "boil off." (This is done in a vacuum, as with a light bulb, so the filament won't burn.)

Next, the electrons must be herded toward the object we wish to examine, which is quite a simple feat: electrons are repelled by negative charge, attracted to positive. The filament (*cathode*) has a negative charge and repels the electrons it generates, and the positive pole of the circuit (*anode*) is between the filament and the specimen. Electrons are drawn toward the anode, which is ring-shaped; but the filaments's charged housing funnels them through the hole, so they don't collide with the anode. Instead, they hurtle toward the specimen. The velocity (and hence the wavelength) of the electrons is determined by the difference in charge — the *potential gradient* — between the anode and cathode, and it's adjustable between one and thirty thousand volts.

Now the random herd of electrons must be focused into a precise, narrow

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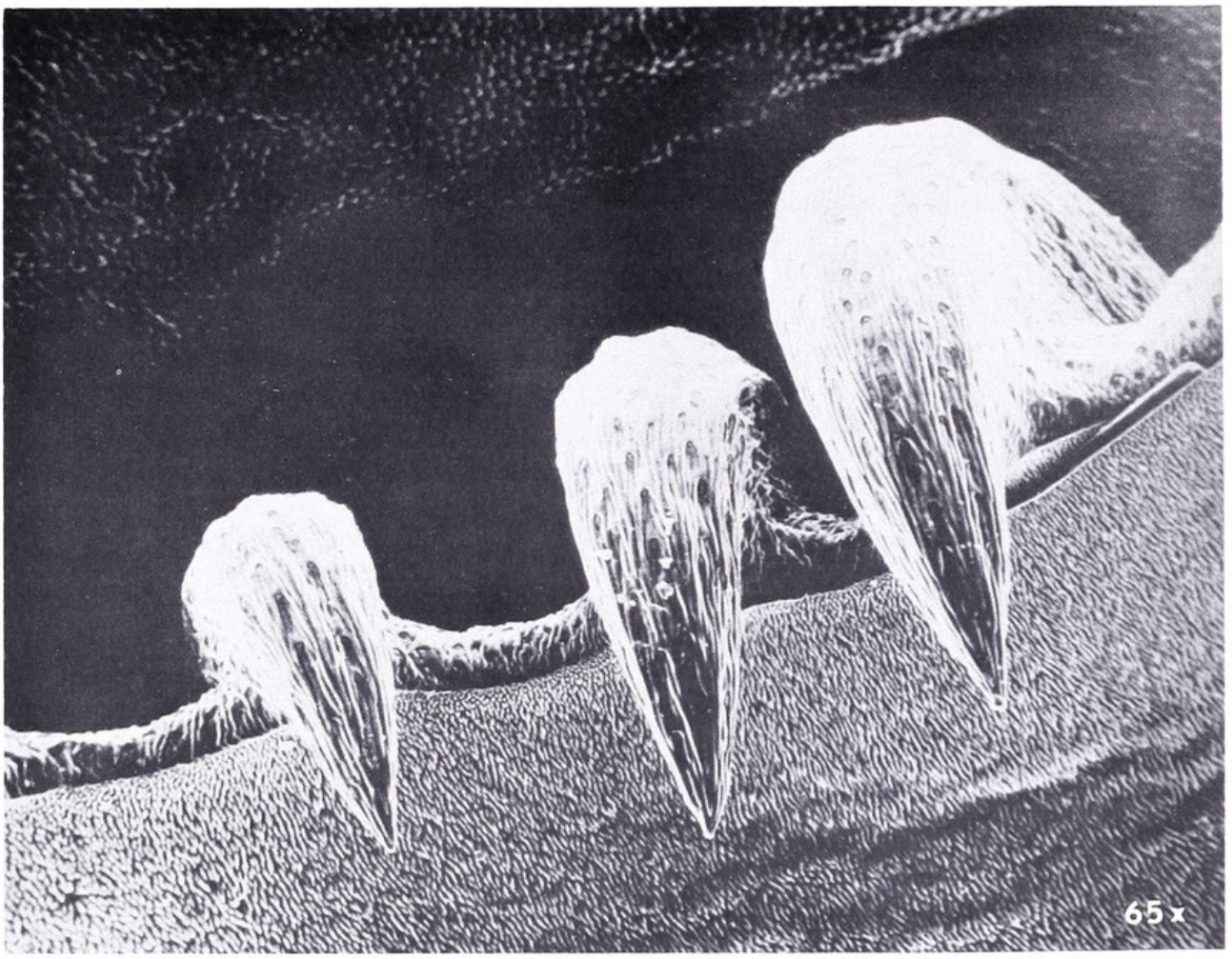
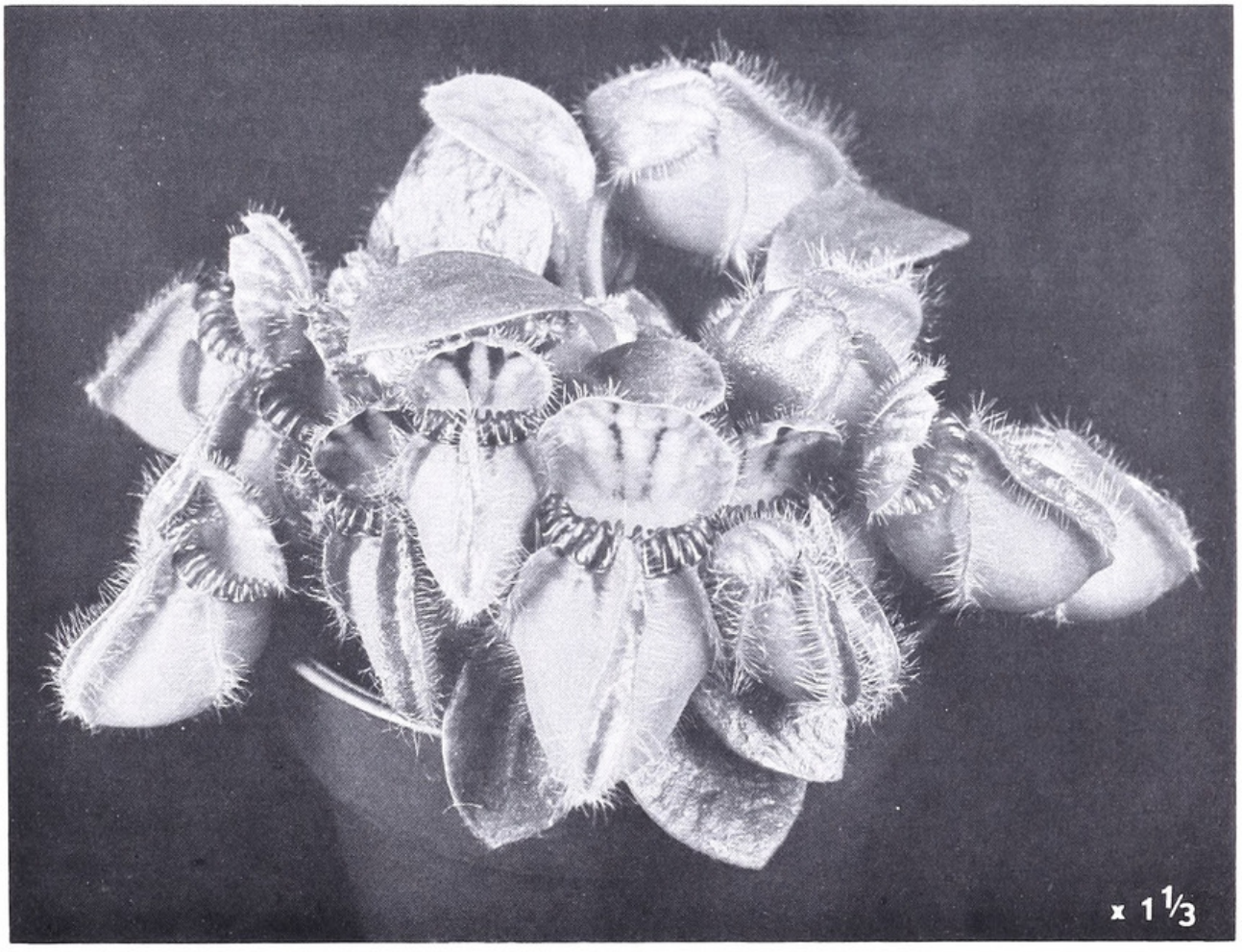
RIGHT

Simplified diagram illustrates SEM's theory. Electrons generated at filament (*top*) are focused into a point on stage (*bottom*). Beam, swayed by scan coils, flies across specimen; the reflected electrons are collected and assembled into a point-by-point display (*right*). [after Everhart and Hayes, 1972]


65x

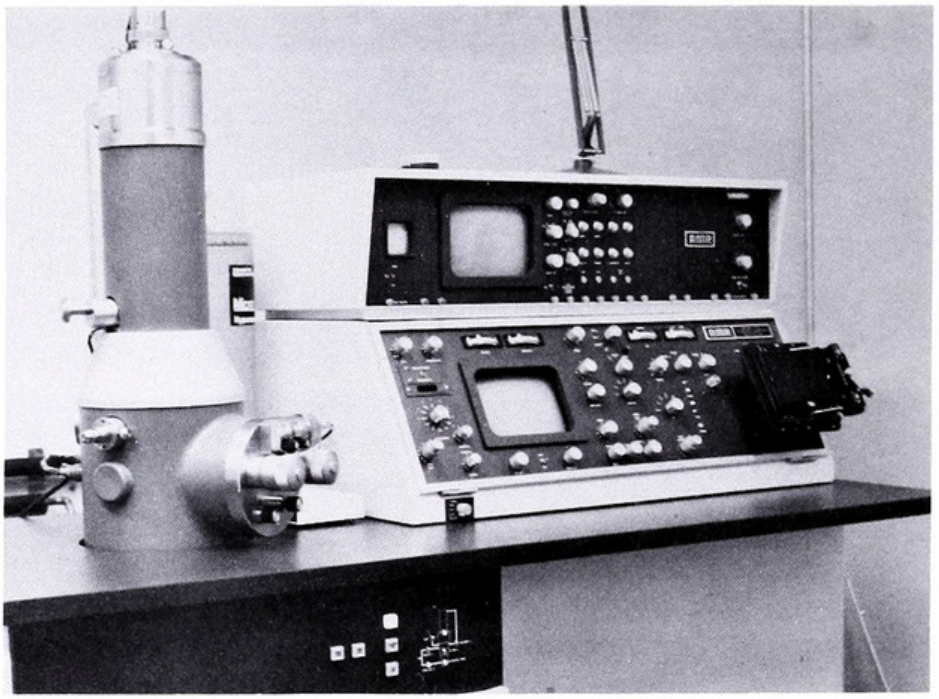

x 1 1/3

beam. Glass lenses cannot be used, as in a light microscope, because electrons won't penetrate glass. But electrons' paths *can* be bent by electromagnetic fields, so electromagnetic lenses are used to focus the electrons.

The electrons which bombarded a specimen are called *primary electrons*. Theoretically, for each primary electron received, the specimen emits a *secondary electron* in exchange. Actually, however, a specimen's surface features affect the number of secondary electrons given off. Valleys and crevices allow few electrons to escape. Peaks and ridges, on the other hand, emit many. And flat surfaces are intermediate. Also, the greater the primary electron beam's incident angle, the more secondary electrons emitted. This is how the SEM depicts topography.

To form an image, the SEM gathers (by means of another potential gradient) the secondary electrons the specimen emits, amplifies them, and displays them as a point on a TV screen. It doesn't focus these secondary electrons into an image, it merely collects them.

How, then, is an image formed? It's built up point by point, as the beam scans over the specimen in a matrix pattern

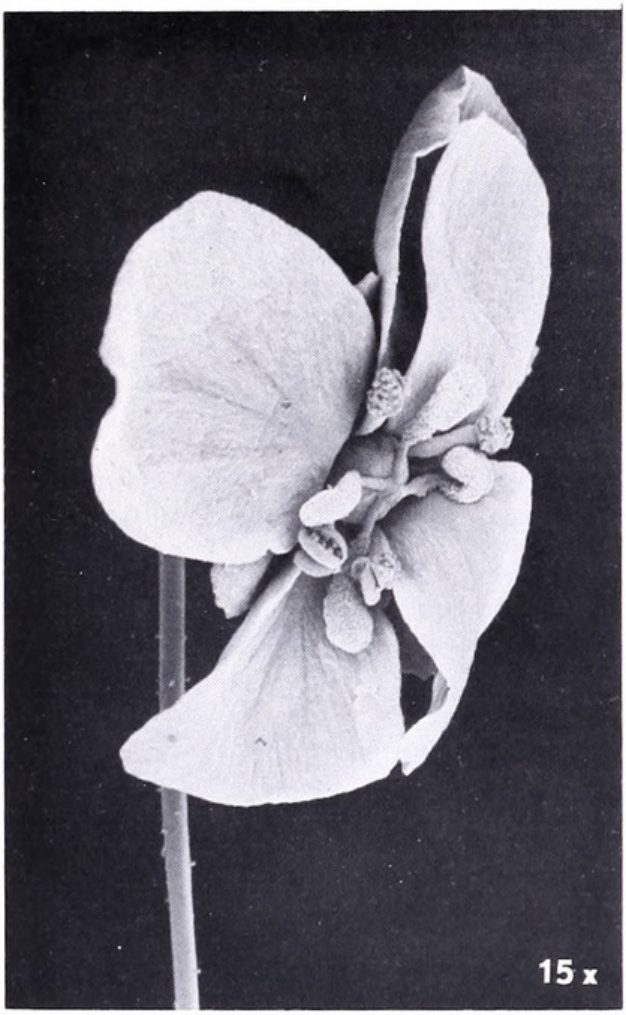


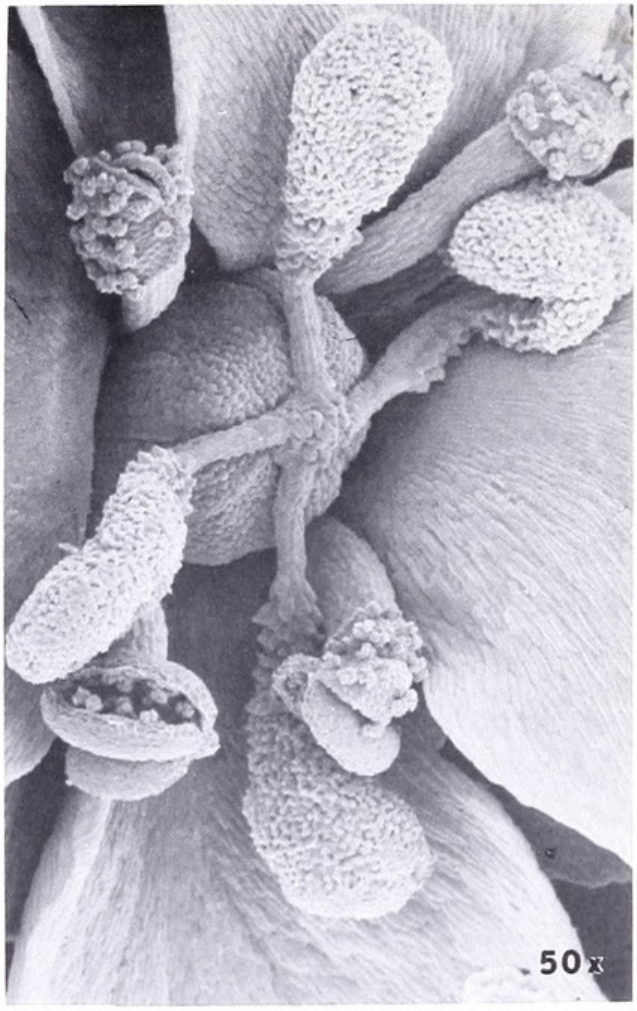
ABOVE

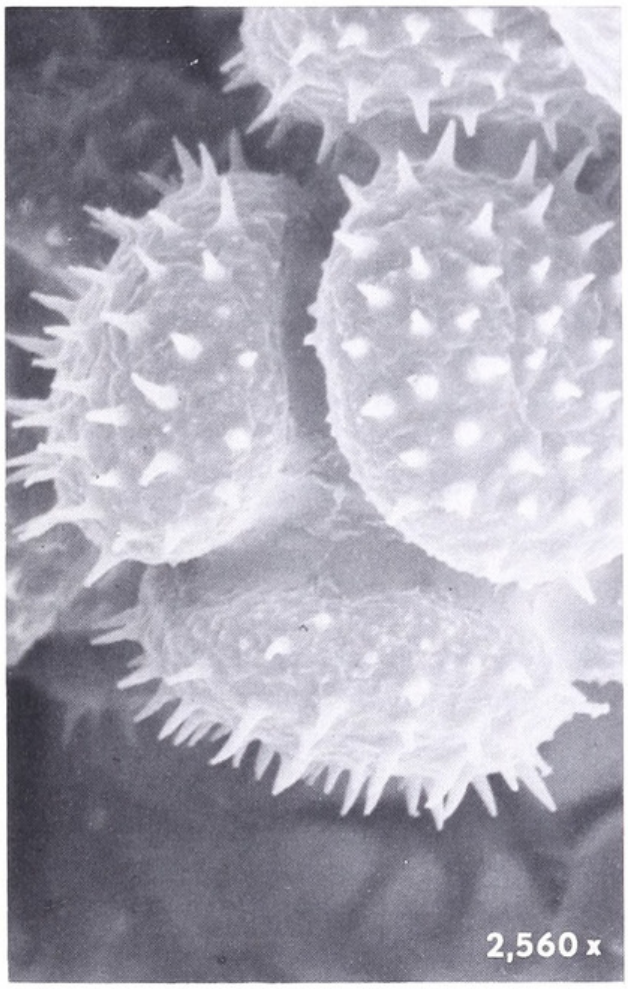
The machine that took the pictures, one of three SEMs currently in operation at Cornell University. Column at left houses electron beam (see diagram); specimens are inserted through port at base; controls on door manipulate position of stage. Console at right is studded with knobs to adjust electron beam, picture, and magnification. Image is viewed on 3 TV screens (polaroid pictures taken from one at far right). Earlier SEMs cost close to $100,000, but advances in electronics halved this figure for newer ones. Table-top models, ca. $10,000, are also available.

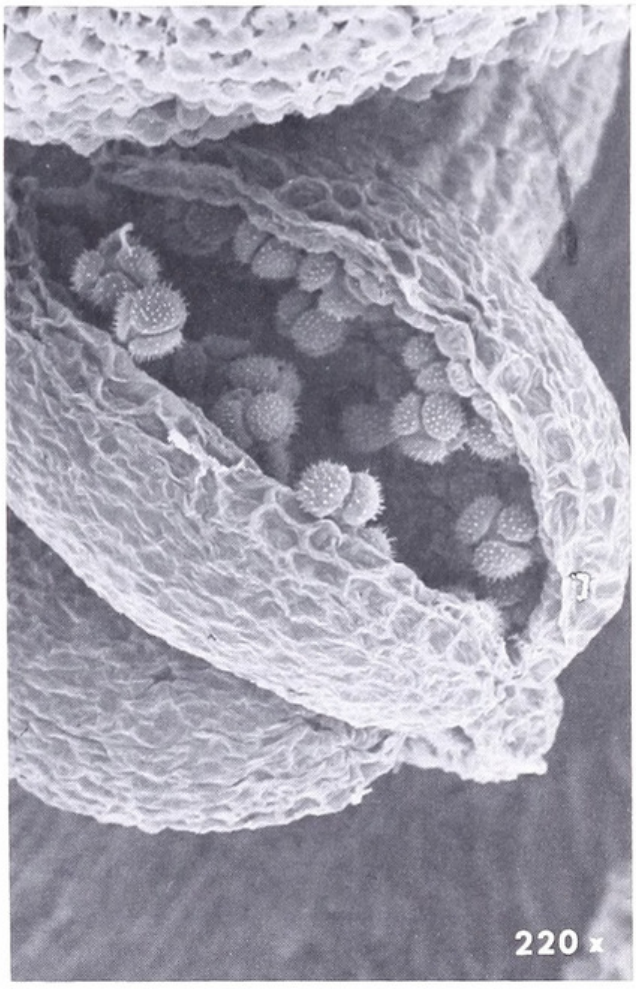
RIGHT

*Drosera paleacea* flower demonstrates the SEM's lower range of magnification (*clockwise, from upper left*): At 15x, the quarter-inch diameter flower looks like it would in an ordinary photograph except for the fine detail and depth. At 50x, individual cells become visible; note also the four-parted style and anthers shedding pollen. Zooming higher, a ruptured anther locule is seen close-up at 220x, and one of its pollen tetrads fills the screen at 2,560x. Machine can attain 400,000x, but resolution becomes limiting; also, most biological specimens look unimpressive above 20,000x.

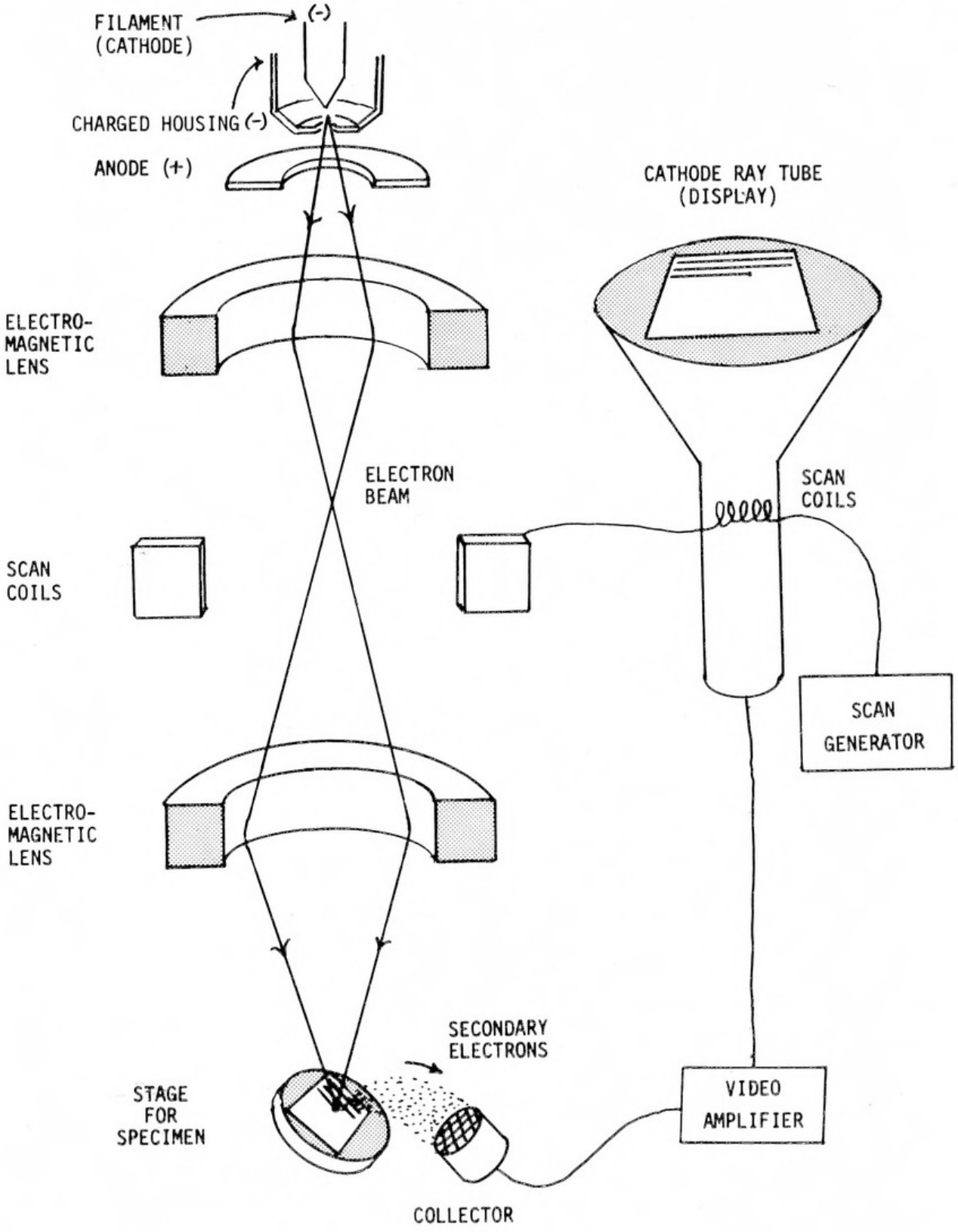

15 x


50 x


2,560 x


220 x

# Simplified Diagram of an S.E.M.



(termed a *raster*). A TV set forms its image in the same way: not by focusing from behind the screen, but with a point-by-point assemblage of light and dark points into lines, and of these lines into a plane. Another analogous image is a newspaper photo, which when examined closely, consists of thousands of light and dark spots.

### Three Main Attributes

Understanding the SEM's operation allows us to account for its attributes. First of all, it has a very high magnification. The way magnification is increased is by having the electron beam scan a smaller area of the specimen, representing this area on the same-sized TV screen.

Another asset of the SEM is its great depth of field — its ability to depict three-dimensional space. The light microscope's focusing system allows it to bring only a narrow plane into sharp focus. Since the SEM's image is not focused, the limitations imposed by focusing do not affect its depth of field.

The third major asset of the SEM is its resolution, which can be defined loosely as a microscope's ability to bring an object into sharp focus. The wavelength of the radiation used is what limits a microscope's resolution. The resolution of a light microscope is limited by the wavelength of light. At magnifications below about 1,000 times, rays of light can be regarded for practical purposes as moving in a straight line. Beyond 1,000 x, however, its relatively long wavelength limits the ability to focus an object sharply.

Electrons have a much shorter wavelength than light. At magnifications above 1,000 times, they can still be regarded as moving in a straight line, and so do not limit an electron microscope's resolution.

### The Aphoristic Perspective

An intimidating array of dials, knobs and switches forms the control panel of the SEM, adding to its science-fiction-like character. The most exciting control is the one marked *magnification.* Merely by turning a knob, it's possible to proceed in steps from a low of 20x, through 50, 100, 50, 1000, all the way up to 100,000 times. Seeing a specimen magnified 60,000 times, we are in a world where an inch, if so magnified, would equal a mile!

Most people come away from their first glimpse of an SEM with a fantastic sense of perspective, and a new appreciation for the microscopic world around us.

Sitting at the SEM and seeing the world as if one inch equalled a mile is really the opposite of jetting along in an airplane and seeing miles go by as if they were inches. Kahlil Gibran's aphorism really puts both feelings into perspective.

### FOR FURTHER READING

Everhart, T., and T. Hayes. 1972. The Scanning Electron Microscope. Scientific American 226(1):54-69.

Dwyer, J. 1974. The SEM — Seeing with a New Kind of Eye. Garden Journal of NYBG 24(2):54-59.

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### LEFT

The SEM's magnification, depth of field, and resolution can impart colossal proportions to Liliputian subjects. Tiny pitchers of *Cephalotus follicularis* (habit photo, *bottom*) appear as menacing "Jaws" of the plant world when rim is viewed from inside (*top*). It's peppered with nectar glands, first seen in this photo. [Taken at the Dudley Observatory, Albany, NY.]

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