Physics 162: Answers to End-of-Class Questions

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In the electron microscopes, the images are in color because the electrons are too small or because the Duke-like worm is too small?

Color is a human perception that your brain creates from light in the visible range of wavelengths (400-700 nm) striking your retina. (There are many experiments that show that color really is created by the brain, e.g., it is easy to shine two wavelengths of light into your eye and your brain will perceive green even though neither wavelength of light corresponds to green.) The electrons in an electron microscope have wavelengths much smaller than this and so are not capable of stimulating your eyes directly, so any image created by an electron microscope cannot be interpreted by your visual system.

What the electron microscope measures is electron intensity (analogous to light intensity) at various locations in space as the electrons scatter off the sample. So the electron microscope produces a big $N \times N$ matrix of numbers, where N may be 2048 or bigger) where each number is the electron intensity at that part of space.

There is no color associated with such a matrix of numbers, so someone wrote a computer program that completely arbitrarily assigned numbers based on guesses as to what would help the human visual system interpret the image.

Can you please explain again why the electric field gets distorted farther away from the center?

I am not sure what is the context of your question, do you mean in the electron microscope? In our discussion in class yesterday, I mentioned that there is a limit to how much an electron microscope or light microscope can see fine details because of a physical effect related to waves called "diffraction" that we will discuss later this semester. Diffraction arises when any kind of wave passes through a hole size, there is an inevitable distortion of the wave caused by the finite width of the hole and this distortion prevents details from being resolved that are smaller than about half the wavelength of the light. The most common way to diminish diffraction is to make the diameter of all holes wider but there there are obvious limits to how wide one can make tubes and lenses.

You can get a quick sense of diffraction by squeezing two adjacent fingers of one hand close together (say your index and middle fingers) and looking at a light bulb through the small slit that appears between the base of these two fingers. As you make that slit smaller and smaller, you will see parallel black bands appearing, which are fringes caused by light diffraction. Some of you may occasionally see so-called "floaters" in your eye when looking at a blue sky without any clouds, these look like small glassy circles stuck together. These are red blood cells close to the surface of your retina, causing a light diffraction pattern.

Why does blurring occur at small wavelengths? Is there a smaller particle that we can use for next generation microscopes?

It is not that blurring occurs at smaller wavelengths but that, because of wave diffraction, there is no benefit to making the wavelengths of electrons smaller and smaller (via a larger potential difference ΔV because, at some point, the blurring because of diffraction prevents one from seeing anything of smaller wavelength.

There is no need for smaller particles, light particles (photons) and electrons can be made to have arbitrarily small wavelengths by making their energy sufficiently high.

Are there any theories about how to see objects smaller than 5 nm, e.g. other than a scanning electron microscope?

The answer is yes. Last year's Nobel prize in Chemistry was awarded to three scientists who had invented an ingenious way called super-resolution light microscopy to see tiny objects using visible light, something that was long thought to be impossible. This discovery allows one to see tiny structures in living biological cells, which is impossible with electron microscopes since any sample in an electron microscope must be dead (coated with a special metal cover to improve the scattering of electrons and then placed in vacuum).

I still have trouble understanding what it means to calculate the electric potential at a point.

The electric potential V is an efficient and useful way to determine how much energy it takes to move a point particle with some known charge q from some place A in space to some other place B in space, namely $q(V(B) - V(A))$ where $V(B)$ is the electric potential at the location B and where $V(A)$ is the potential at location A.

To "calculate the electric potential at a point" means to calculate how much work it takes to move a unit charge $q = 1$ from some reference point to the point of interest in the presence of an electric field produced by some group of charged objects. The reference point is completely arbitrary, often being chosen to be infinitely far away for a point charge or group of point charges, or just some arbitrary point in space for some finite-size objects like spheres or cylinders. If P_R is the reference point, you then get the potential V at some arbitrary point in space by evaluating the line integral

$$V(x, y, z) = V(P) = V(P_R) - \int_{P_R}^{(x,y,z)} \mathbf{E} \bullet d\mathbf{l}, \tag{1}$$

where $V(P_R)$ is some arbitrary constant, which one can often set to zero for simplicity. For many simple cases, the line integral can be evaluated analytically, for more complicated cases a computer code can easily approximate the line integral for any desired location.