A Conversation Between Dr. Bob and Yew

Yew: What lens is that?
Bob: It’s a 63 X, 1.4.
Yew: 63 X I get, but what’s the 1.4?
Bob: It’s the lenses numerical aperture or NA.
Yew: What’s that mean?
Bob: It tells you the lenses resolving power. Divide the NA into 300 and you get the lenses resolution in nanometers using blue light. In general, the bigger the NA the better the lens.
Yew: Oh. What’s that lens?
Bob: It’s a 100 X, 1.3.
Yew: How come the 100 X has a lower NA that the 63 X?
Bob: The NA doesn’t depend on the magnification of the lens. It depends on the angle of the light cone the lens can accept and on the refractive index of the medium in front of the lens.
Yew: What does that mean?
Bob: You really want to know this?
Yew: Yes!
Bob: OK. Picture a tiny light source suspended in space. It gives off light in all directions. The light makes a sphere around the source. Now, hold a circular lens toward the source. The lens is lit by part of the light sphere. If you imagine tracing that part back to the source, you see it makes a cone of light. OK?
Yew: OK.
Bob: If the lens is a bigger one, the angle of the sides of the cone is bigger. The same is true if the lens moves closer to the source. That’s what is meant by the light cone. The angle that the sides of the cone make is called the angular aperture of the lens. Got it?
Yew: Yes, but what about the refractive index?
Bob: OK. When a light beam goes from a material of one density (say air) to a material of a different density (say water) it will shift a little from its normally straight path. This is called refraction. The amount that the light shifts determines the refractive index of the material. For example the refractive index of air is 1 and the refractive index of water is 1.33.
Yew: OK, but how are the refractive index and the light cone related?
Bob: Well, go back to holding your lens up to the light source. Pretend that you can see only the cone of light coming to your lens from the source. Now imagine that the refractive index of the material in between the light source and your lens goes up, say form air to water. The size of the circle of light on your lens will get smaller.
The unlit part of your lens is available to receive more light. So, all pretenses aside, your lens can actually receive more light looking through water than through air. That’s how the refractive index and the light cone are related. So you see, as the refractive index goes up, the NA goes up.

Yew: So, why does having a bigger NA give you better resolution?
Bob: Well, this has to do with diffraction.
Yew: What’s diffraction?
Bob: Imagine that you have a specimen on a microscope and the specimen consists of tiny parallel slits of varying widths. As light rays from the condenser pass though the slits they get bent a little from their straight path. This is not due to a change in refractive index, it is due to the size of each slit relative to the wavelength of the light. Narrow slits bend the light more than wider ones. This type of bending of light is called diffraction. If you picture the slits as making their own light cones- as if they were sources of light form the objective lenses point of view -the cone from a smaller slit would be wider than the cone from a bigger slit. So smaller objects diffract light at a bigger angle than larger objects.

Yew: What’s the connection to resolution?
Bob: If a cone is wider than your lens can accept, you won’t see the object that made it very clearly - or at all. As the refractive index goes up, the angle of the diffracted light cones from the slits get narrower so the light from a smaller slit will be more likely to fit into your lens and that object will be resolved.

Yew: Hummmmm. One final question: Why is it 63 X instead of 60 X?
Bob: This is one of the arcane things in microscopy. There is an international standard geometric series of magnifications for light microscopes called the Ra-10 standard series of the ISO. It tries to make each succeeding step in magnification about 25% different from its neighbors and the product of any two values to be a standard value. The values in the series that we are most familiar with are 10, 12.5, 16, 20, 25, 32, 40, 50, 63, 80 and 100.

Yew: I see.
Bob: By the way, Ernst Abbe created the concept of Numerical Aperture. His equation is \( NA = n \sin \alpha \) where \( n \) is the refractive index and \( \alpha \) is half the angular aperture of the lens. He also defined a resolution equation which says that resolution \( D \) is equal to the wavelength of light divided by two times the NA or \( D = \lambda / 2NA \). Abbe’s equation is based on linear objects just like the slits we talked about. Later on Lord Rayleigh revised Abbe’s equation based on points as objects which says \( D = 1.22\lambda / \text{NA condenser times NA objective} \).

Yew: Who is Ernst Abbe? …