Problem Set #4

1. Describe the physics involved in the electron sources and electron lenses used in a modern electron microscope. You should include, amongst other things: a comparison of the advantages and disadvantages of the three types of common electron sources: tungsten hairpin, LaB_6 and field emission gun;the action of an electro-magnetic lens in focusing electrons, including how the rotation and focal length of a magnetic lens change as either the magnetic induction of the lens or the energy of the electrons passing through a lens is changed; the way beam shifts and tilts work.

2(i). An electron probe of 10nm diameter with a convergence semi-angle α of 5×10^{-3} radians is formed in a 35 keV SEM. Ignoring any lens aberration effects, calculate how many electrons pass through the probe per second, if the electron source brightness $\beta = 10^{10}$ amps m^{-2} sr^{-1}.

(ii). Calculate the theoretical size (resolution), d(min), of the spot onto which a scanning electron microscope beam can be focused if the objective lens has a spherical aberration, C_s, coefficient of 1 cm, and a chromatic aberration coefficient, C_c, of the same magnitude for an effective probe semiangle,α , of 0.003 radians. The desired incident beam current, I_o, is 2×10^{-12} amp for an accelerating potential, E, of 20 kV, and a tungsten cathode temperature, T, of 2300°C. (Assume a voltage stability, $\Delta E/E$, of 1×10^{-5}.)

d(min) is given, in general for a thermionic emitter, by a combination of four terms as shown in the equation below. The first term represents a space charge limitation on the spot size, that is, as the current I_o in the spot is increased the electrons come closer together and so repel each other more. The second and third terms are due to the spherical and chromatic lens aberrations. The final term is the diffraction-limited spot size, where Δr_d is the radius of the disc of confusion based on a Rayleigh criterion.

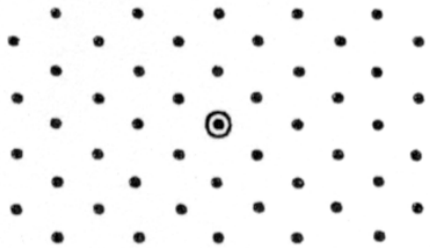
$$d(\min) = \sqrt{\frac{6 I_o k T}{\pi J_o e E \alpha^2} + \left(\frac{C_s \alpha^3}{2}\right)^2 + \left(C_c \frac{\Delta E \alpha}{E}\right)^2 + 4\Delta r_d^2}$$

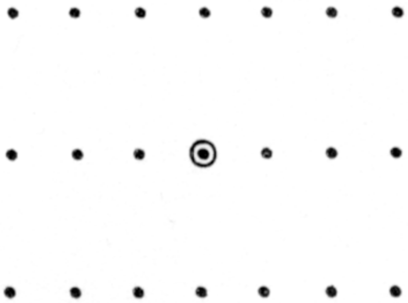
where k is Boltzmann's constant and J_o, the current density at the cathode corresponding to temperature T, is given by the Richardson-Dushman equation:-

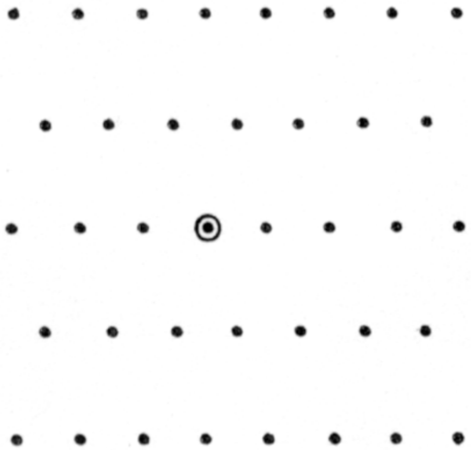
$$J_o = \frac{4\pi m k^2 e T^2}{h^3} \exp \frac{-E_w}{kT}$$

where h is Planck's constant, m is the electronic mass, e the electronic charge and E_w is the work function of the thermionic emitter.

3.Index the idealized electron diffraction (spot) patterns below, indicating the approximate beam normal in each case. a-1 and a-2 are fcc, b-1 and b-2 are bcc and c-1 and c-2 are ideal hcp. The large central spot represents the transmitted beam.


(a-1)


(a-2)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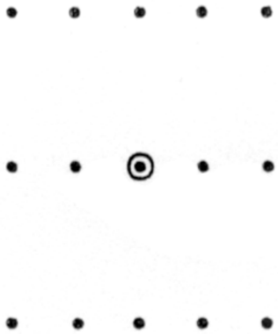
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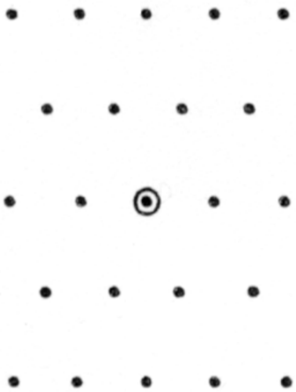
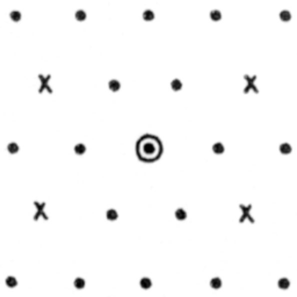

(c-1)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