NANO 703/703L
Homework 2
Due: M-10/3, 10:00 AM

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1) Briefly describe the following terms:

a) bremsstrahlung X-rays
b) characteristic X-rays
c) Auger electrons
d) secondary electrons

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2) An electron source has brightness $\beta = 3.6\times10^{8}\ \mathrm{A}/\left(\mathrm{cm}^2\cdot\mathrm{sr}\right)$.

a) An image of the source at point 1 has diameter $d_1 = 0.62\ \mu\mathrm{m}$ and semi-angle of convergence $\alpha_1 = 8.2\ \mathrm{mrad}$. Find the probe current i_1

b) A second image of the source at point 2 has diameter $d_2 = 29\ \mathrm{nm}$ and current $i_2 = 8.5\ \mu\mathrm{A}$. Find the semi-angle of convergence α_2 (in mrad) at point 2.

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3) An electron probe with lateral diameter $d = 72\ \mathrm{nm}$ diverges at a semi-angle $\alpha = 18.0\ \mathrm{mrad}$ at a distance $p = 0.96\ \mathrm{cm}$ in front of a lens with focal length $f = 0.68\ \mathrm{cm}$. In back of the lens, find:

a) The image distance *q*,
b) the lateral magnification *M*,
c) the lateral size d' of the image,
d) the angular magnification M_θ;
e) The convergence semi-angle α' of the image of the probe;

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4) Find the net force on charge $q = -2.0\ \mathrm{nC}$ with velocity $\mathbf{v}$ and magnetic field $\mathbf{B}$ given by:

a) $\mathbf{v} = -(0.66c)\hat{\mathbf{z}}$, $\mathbf{B} = (0.80\ \mathrm{T})\hat{\rho} + (5.8\ \mathrm{T})\hat{\mathbf{z}}$;

b) $\mathbf{v} = (0.0089c)\hat{\phi} - (0.66c)\hat{\mathbf{z}}$, $\mathbf{B} = (5.8\ \mathrm{T})\hat{\mathbf{z}}$

(Note that $\hat{\rho}\times\hat{\phi} = \hat{\mathbf{z}}$. Also $1\ \mathrm{T} = 1\ \frac{\mathrm{N}}{\mathrm{A}\cdot\mathrm{m}}$.) Your answers should be vectors with units of N.

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5) Consider an objective lens with spherical aberration coefficient $C_s = 1.8\ \mathrm{mm}$ and a semi-angle of collection $\beta = 6.0\ \mathrm{mrad}$ acting on electrons with energy 200 KeV.

a) What is the diffraction limit δ_d on the resolution?
b) What is the spherical-aberration limit δ_s on the resolution?
c) What is the *combined* resolution limit δ_{net}, including both diffraction and spherical aberration?
d) What is the *optimal* semi-angle of collection β_{opt} of the lens?
e) What is the *practical* resolution $\delta_{\min}$ of the lens?

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6) Find expressions for the intensities $I(\mathbf{r}) = \left|\psi(\mathbf{r})\right|^2$ of the wave functions below.

($\mathbf{k}$, $\mathbf{K}$, and $\mathbf{r}$ are real):

a) $\psi(\mathbf{r}) = A\mathrm{e}^{2\pi i\mathbf{k}\cdot\mathbf{r}+i\phi}$, ($A$, ϕ real)

b) $\psi(\mathbf{r}) = i\cdot\cos(\theta)\cdot\frac{\mathrm{e}^{2\pi ikr}}{r}$, [$\theta$ is real]

c) $\psi(\mathbf{r}) = \mathrm{e}^{2\pi i\mathbf{k}\cdot\mathbf{r}}\mathrm{e}^{-\mathbf{K}\cdot\mathbf{r}/2}$,

d) $\psi(\mathbf{r}) = \frac{2}{5}\cdot\mathrm{e}^{2\pi i\mathbf{k}\cdot\mathbf{r}} + i\cdot\frac{\sqrt{21}}{5}\cdot\mathrm{e}^{-2\pi i\mathbf{k}\cdot\mathbf{r}}$