PHOTON ENERGY: $E = hv$ (joules)

h = Planck's constant ($6.624\text{x}10^{-34}$ joule-sec)
v = frequency (cycles/sec)

ELECTRON WAVELENGTH (nms): $\lambda = h/mv$

m = electron mass ($9.11\text{x}10^{-28}$ g)
v = electron velocity

$$l = \frac{1.23}{\cdot\sqrt{V}}\, nm$$

V = accelerating potential (volts)

$$l = \frac{1.23}{\sqrt{V + 10^{-6}V^2}}$$ with relativistic correction

RESOLUTION

Diffraction Effect (Rayleigh criteria): $d_d = 0.61\lambda/n \cdot \sin\alpha$

λ = wavelength of the radiation
n = refractive index of the media between object and lens
α = semi-angular aperture of the lens

Spherical Aberration Limit: $d_s = C_s\alpha^3/2$

C_s = spherical aberration coefficient of the lens
α = semi-angular aperture of the lens

Chromatic Aberration Limit: $d_{cv} = C_c \cdot \alpha_o \cdot \Delta V/V$ or $d_{ci} = 2C_c \cdot \alpha_o \cdot \Delta I/I$

d_{cv} = separation of two object points which are just resolved, considering voltage
d_{ci} = separation of two object points which are just resolved, considering current
C_c = chromatic aberration coefficient of lens (usually 1-3 mm)
α_o = objective semi-angular aperture angle
V = accelerating potential
ΔV = maximum departure from V of electrons contributing to the image
I = lens current
ΔI = maximum departure from I

Astigmatism: $d_a = (\lambda \cdot \Delta f)^{1/2}$

λ = wavelength of electron
Δf = maximum difference in the focal length of the asymmetric lens

BASIC LAWS OF CLASSICAL GEOMETRICAL OPTICS

1. Rectilinear propagation of light in medium of constant refractive index (n).
2. Law of reflection: $i = r$ (i = angle of incidence; r = angle of reflection)
3. Law of refraction (Snell's Law): $\sin(i)/\sin(r) = n_2/n_1$
4. Independence of rays (Assume light rays travel independently).

LENS FORMULA (THIN LENS EQUATION): $1/f = 1/o + 1/i$

f = focal length of the thin lens (same on both surfaces)
o = distance of object from lens (positive to the left)
i = distance of image from the lens (positive to the right)

MAGNETIC FIELD INDUCED BY A CURRENT

The **right hand rule** states that the thumb points in the direction of **current flow** and fingers curl in the direction of the magnetic field (toward N pole).

MAGNETIC FLUX DENSITY IN A SOLENOID: $B = \mu(N \cdot I/l) = \mu H$

μ = permeability of surrounding material
H = magnetic field intensity = $(N\,I/l)$
N = number of turns of wire in the coil
I = current strength in the wire
l = length of the solenoid

FORCE ON A CURRENT MOVING THROUGH A MAGNETIC FIELD

Right hand rule: Middle finger points in the direction of **electron** flow, first finger points in the direction of the magnetic field and thumb points in the direction of the force on the moving electron.

MAGNETIC LENS FOCAL LENGTH: $f = KV_r/(N \cdot I)^2$

f = focal length of the lens
K = a constant
V_r = the accelerating voltage, relativistically corrected
$N \cdot$I = number of ampere turns in the excitation coils

THERMIONIC EMISSION (Richardson's equation): I_s (amps/cm^2) $= AT^2 e^{-(b/T)}$

A, b = constants determined empirically
T = temperature

OHM'S LAW: $V = I \cdot R$

V = voltage (volts)
I = current (amps)
R = resistance (ohms)

DEPTH OF FIELD: $D_o = d/\tan\alpha$

d = the minimum object spacing one hopes to resolve
α = the semi-angular aperture of the lens.

DEPTH OF FOCUS: $D_i = M^2 d/\tan\alpha = D_o M^2$

M = magnification of the lens (or complete lens system)

CONTRAST: % contrast $= 100 * |I_b - I_o| / I_b$

I_b = intensity of background ajacent to the object point
I_o = intensity of object point

ELECTRON SCATTERING ANGLE

Nuclear (elastic) scattering: $\theta_n = Ze/Vr_n$

Electron (inelastic) scattering: $\theta_e = e/Vr_e$

Z = the atomic number
e = the charge of an electron
V = the accelerating voltage
r_n = distance of the beam electron from the atomic nucleus
r_e = distance of the beam electron from the atom electron

GUN BRIGHTNESS: $B = \rho_c eV/kT$

- ρ_c = current density in the cathode
- e = electronic charge
- V = accelerating voltage
- k = Boltzmann's constant (8.6×10^{-5} eV/°K)
- T = temperature

PHOTOGRAPHIC EMULSIONS Optical Density: $D = \log_{10}(1/T)$

- T = I_t/I_i is the fraction of incident light **transmitted** by the plate or film.
- I_i = intensity of incident light
- I_t = intensity of transmitted light

Density vs. Exposure: $D = D_S(1\text{-}e^{-KE})$, where $K = na$

- n = #grains/e^-
- a = the area of one developed grain
- E = exposure time
- D_S = saturation density of emulsion

In the region where $D < D_S/4$, the curve is approximately linear, so $D = D_S KE$

Contrast: $\gamma = \Delta D/\Delta \log E$

With **electrons,** in the linear region of the D vs. E curve, contrast is linearly related to density (i.e. $\Delta D/\Delta \log E = 2.3D$)

Electron range in emulsions: $R = V^2/100$, where V = voltage in kV.

Granularity is proportional to $1/\sqrt{N}$, where N = the number of electrons.

Electron Noise is proportional to $\sqrt{N}$.

Photographic Noise Amplification is proportional to $(1+(2/n))^{1/2}$, where n = number of grains produced per quantum event.

Signal-To-Noise Ratio (S/N) is proportional to $N/\sqrt{N} = \sqrt{N}$

Detective Quantum Efficiency (DQE)

$$\text{DQE} = \frac{\left(\frac{s}{n}\right)^2_{\text{out}}}{\left(\frac{s}{n}\right)^2_{\text{in}}}$$

where S/N = visibility of a given size detail against a grainy background
"out" = refers to the photographic image
"in" = refers to the electron image.

ELECTRON DIFFRACTION

Bragg's Law: $n\lambda = 2d\sin\theta$

n = integer
λ = electron wavelength
d = crystal lattice spacing between atomic planes
θ = angle of incidence and also of reflection

Camera constant = $\lambda \cdot L$, where L = **camera length** (usually expressed in mm)

Determination of lattice spacings, d, **from electron diffraction:** $D = L \cdot \tan(2\theta)$

D = distance measured from center of diffraction pattern to spot or circular ring arising from diffraction from a set of lattice planes of spacing, d.

Since, for small θ $\tan(2\theta) = 2\theta = \sin(2\theta)$,

$D = 2L\theta$, and from Bragg's law for small θ,
$2\theta = n\lambda/d$, thus, $d = n\lambda L/D$

STEREO MICROSCOPY: $\sin(\theta/2) = P/2tM$

θ = full angle of tilt between stereo pairs
P = parallax
t = specimen thickness
M = magnification

METAL SHADOWING

Metal thickness: $w = m/4\pi R^2$

w = mass per unit area deposited
m = total mass evaporated
R = distance of the specimen from the source

Metal shadowing length: $h = l \cdot \tan\theta$

h = height of feature casting the shadow
θ = angle of shadowing
l = length of shadow