Engineering Study Sheet

Based off sample QE questions

January 17, 2026

1 Heat Transfer

Important Numbers

$$\text{reynold's number: } Re = \frac{UD}{v} \tag{1}$$

$$\text{nusselt number: } \bar{N}u_D = \frac{hD}{k} \tag{2}$$

Convection Equations

Use a differential control volume where energy is conserved. Do not forget to multiply by surface area to convert between flux and energy.

$$\text{Convective Energy} \quad E = \dot{m}C_p\Delta T \tag{3}$$

$$\text{Convective Heat Transfer} \quad q'' = h(T_s - T_m) \tag{4}$$

$$\text{Rate of Heat Transfer} \quad q = \int_{SA} q'' \tag{5}$$

$$q = hA(T_x - T_\infty) \tag{6}$$

$$\text{film temperature: } T_f = \frac{T_s + T_\infty}{2} \tag{7}$$

Conduction Equations

$$\text{fourier's law: } q_x = -kA(x)\frac{dT}{dx} = \text{constant} \tag{8}$$

$$\frac{d^2T}{dx^2} + \frac{\dot{q}}{k_a} = 0 \tag{9}$$

Thermal Resistance Networks

Make sure to draw the network to make sure not to miss any point.

$$\text{conduction: } R'' = \frac{L}{k} \tag{10}$$

$$\text{convection: } R'' = \frac{1}{h} \tag{11}$$

$$\text{rate of heat loss per unit area: } q'' = \frac{T_s - T_\infty}{R''_{total}} \tag{12}$$

2 Thermodynamics

$$\text{Efficiency} \quad \eta = \frac{W}{Q_{in}} \tag{13}$$

$$\text{Heat Engine First Law} \quad Q_{in} = W + Q_{out} \tag{14}$$

$$\text{Change in Entropy} \quad \Delta S = \frac{Q}{T} \tag{15}$$

$$\text{Carnot Efficiency} \quad \eta_{carnot} = 1 - \frac{T_{low}}{T_{high}} \tag{16}$$

3 Fluid Mechanics

Cartesian Navier-Stokes

$$\text{Cartesian Navier-Stokes in x Direction} \quad \rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\frac{\partial^2 u}{\partial y^2} \tag{17}$$

$$\text{Common Assumptions:} \tag{18}$$

$$\text{Steady Flow:} \quad \frac{\partial u}{\partial t} = 0 \tag{19}$$

$$\text{Fully Developed Flow:} \quad \frac{\partial u}{\partial x} = 0 \tag{20}$$

$$\text{No velocity in y:} \quad v = 0 \tag{21}$$

$$\text{Constant Pressure Gradient:} \quad \frac{\partial p}{\partial x} = -G \text{ (where G is a constant)} \tag{22}$$

$$\text{No Slip:} \quad u(0) = u(h) = 0 \tag{23}$$

4 Solid Mechanics

Stress and Strain

$$\text{Engineering Stress} \quad \sigma_{eng} = \frac{F}{A_0} \tag{24}$$

$$\text{True Stress} \quad \sigma_{true} = \frac{F}{A_i} \tag{25}$$

$$\text{Engineering Strain} \quad \epsilon_{eng} = \frac{\Delta L}{L} \tag{26}$$

$$\text{True Strain} \quad \epsilon_{true} = \ln\frac{L_i}{L_0} = \ln\left(1 + \epsilon_{eng}\right) \tag{27}$$

Conservation of Volume

During deformation, volume is conserved.

$$A_0 L_0 = A_i L_i \tag{28}$$

Flow Curve

$$\sigma = K\epsilon^n \tag{29}$$

The Considere Criterion states that necking begins when:

$$\frac{d\sigma}{d\epsilon} = \sigma \tag{30}$$

$$\rightarrow n = \epsilon \tag{31}$$

Axial Loading

$$\text{axial deformation: } \delta = \frac{PL}{AE} \tag{32}$$

Springs act in series:

$$\frac{1}{k_{total}} = \frac{1}{k_1} + \frac{1}{k_2} + ... + \frac{1}{k_n} \tag{33}$$

The general approach for beam bending problems is to use sum of moments and sum of vertical and/or horizontal forces to solve for unknown reaction forces. For shear and bending moment diagrams, make "cuts" right after each support to determine what to put on the plot.

Beam Loading

$$\text{centroid: } \bar{y} = \frac{\sum A_y y_i}{\sum A_i} \tag{34}$$

$$\text{parallel axis theorem: } I_1 + A_1 d_1^2 + I_2 + A_2 d_2^2 \tag{35}$$

$$\text{bending stress: } \sigma = \frac{Mc}{I} \tag{36}$$

$$\text{for rectangular cross sections: } I = \frac{1}{12} bh^3 \tag{37}$$

$$\text{cantilever beam deflection: } \delta = \frac{PL^3}{3EI} \tag{38}$$

5 Manufacturing

Direct Extrusion

$$\text{johnson formula: } a + b\ln(r_x) \tag{39}$$

$$\text{for round cross sections: } r_x = \frac{A_0}{A_f} = \frac{D_0^2}{D_f^2} \tag{40}$$

$$\text{flow stress: } \bar{Y}_f = \frac{K\epsilon_x^n}{1+n} \tag{41}$$

$$\text{extrusion pressure: } \bar{Y}_f \epsilon_x (1 + \frac{L}{D_0}) \tag{42}$$

6 Dynamics

the hardest part of these problems is choosing to use Newtonian mechanics or energy methods. In general, if you need to find any kind of velocity in the system, energy methods will be much easier!

Energy Equations

$$\text{potential energy: } PE = mgh \tag{43}$$

$$\text{kinetic energy: } KE = \frac{1}{2}mv^2 \tag{44}$$

Rotating Bodies

$$\text{velocity relation: } v = \omega r \tag{45}$$

$$\text{acceleration relation: } a = \alpha r \tag{46}$$

$$\text{kinetic energy rotating about fixed axis: } KE = \frac{1}{2}I\omega^2 \tag{47}$$

$$\text{torque equation: } \sum T = I\alpha \tag{48}$$

Mass Moment of Inertia

$$\text{definition: } I = \int r^2 dm \tag{49}$$

$$\text{thin rod: } I_{center} = \frac{1}{12}mL^2, \quad I_{end} = \frac{1}{3}mL^2 \tag{50}$$

7 Vibrations

Mechanical Modeling

Use Newton's Second Law literally everywhere.

$$F_{total} = m\ddot{x} \tag{51}$$

$$\text{spring force: } F_s = k\Delta x \tag{52}$$

$$\text{friction force: } F_f = b\dot{x} \tag{53}$$

$$\text{damping force: } F_d = c\dot{x} \tag{54}$$

8 Controls

Transfer Function

$$\text{closed loop TF: } T(s) = \frac{Y(s)}{R(s)} = \frac{G(s)}{1 + G(s)} \tag{55}$$

Steady State Error

In general, use final value theorem:

$$\text{error signal in s-domain: } E(s) = R(s) - Y(s) = \frac{R(s)}{1 + G(s)} \tag{56}$$

$$\text{final value theorem: } e_{ss} = \lim_{s \to 0} sE(s) = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)} \tag{57}$$

For a unit step response:

$$e_{ss} = \frac{1}{1 + K_p} \tag{58}$$

$$K_p = \lim_{s \to 0} G(s) \tag{59}$$

For a unit ramp step:

$$e_{ss} = \frac{A}{K_v} \tag{60}$$

$$K_v = \lim_{s \to 0} sG(s) \tag{61}$$