Problem 1:
(D) $Mv = mv'$, $v' = Mv/m$. $W = ½(Mv^2 + mv'^2)$
$W = ½(Mv^2 + (M^2/m)v^2)$

Problem 2:
(C) Doppler shift, moving observer,
$f' = f_0(v - v_{obs})/(v - v_s)$
where v_{obs} and v_s are not the speeds, but the components of the observer's and the source's velocity in the direction of the velocity of the sound reaching the observer.

Problem 3:
(D) Statements (A), (B), and (E) are true for all central potentials, statement (C) is true for the given potential. Stationary elliptical orbits with the sun at one focus are a signature of an attractive $1/r^2$ force.

Problem 4:
(C) Harmonic oscillator: $E_n = (n + ½)hf$.

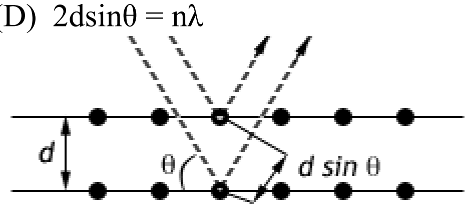
Problem 5:
(A) A mass at l and a mass at l' produce a net restoring torque
$\tau_{net} = -mgl\sin\theta - mgl'\sin\theta \sim -mg\theta(l + l')$
Pure rotation: $\tau = I\, d^2\theta/dt^2 = m(l^2 + l'^2)d^2\theta/dt^2$. Here $\tau = -mg(l + l')\theta$.
$d^2\theta/dt^2 = -g(l + l')\theta/(l^2 + l'^2)$, $\omega = (g(l + l')/(l^2 + l'^2))^{1/2}$.
$\omega_2/\omega_1 = ((l_1^2 + l_1'^2)(l_2 + l_2')/[(l_2^2 + l_2'^2)[l_1 + l_1']])^{1/2}$.
$\omega_2/\omega_1 = (2*3/2)/((5/4)*2)^{1/2} = (6/5)^{1/2}$.

Problem 6:
(C) $(\hbar/i)\partial\psi/\partial x = p_x$

Problem 7:
(C) Gauss' law: The magnitude of the gravitational force decreases as $1/r^2$ outside a spherically symmetric mass distribution.

Problem 8:
(C) Gauss' law: inside a homogeneous sphere the magnitude of the force increases linearly.

Problem 9:
(D) $2d\sin\theta = n\lambda$

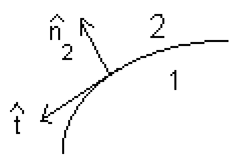


Problem 10:
(C) Invariance of the space-time interval:
$c^2\Delta t^2 - \Delta x^2$ is the same in every reference frame.
$0 - c^2*9\ \text{min}^2 = c^2\Delta t'^2 - c^2*25\ \text{min}^2$. $\Delta t' = 4$ min.

Problem 11:
(A) Ampere's law

Problem 12:
(D) These equation would contain source terms due to magnetic current and charge densities.

Problem 13:
(D) Plane waves at boundaries:



Boundary conditions, SI units:
$(\boldsymbol{D}_2 - \boldsymbol{D}_1)\cdot\hat{\boldsymbol{n}}_2 = \sigma_f$, $(\boldsymbol{B}_2 - \boldsymbol{B}_1)\cdot\hat{\boldsymbol{n}}_2 = 0$, $(\boldsymbol{E}_2 - \boldsymbol{E}_1)\cdot\hat{\boldsymbol{t}} = 0$, $(\boldsymbol{H}_2 - \boldsymbol{H}_1)\cdot\hat{\boldsymbol{t}} = \boldsymbol{k}_f\cdot\hat{\boldsymbol{n}}$.
Inside the conducting walls **E** and **B** are zero

Problem 14:
(C) Motion of the center of mass: $\mathbf{V} = (2mv - mv)/(2m)\mathbf{i} = (v/2)\mathbf{i}$, $X = Vt = vt/2$, $Y = 0$
Motion about the center of mass: $L = 3mvb/2 = I\omega = (mb^2/2)\omega$, $\omega = 3v/b$.
$x' = (b/2)\sin(\omega t)$, $y' = (b/2)\cos(\omega t)$. $x = X + x'$, $y = Y + y'$.

Problem 15:
(B) 25000 eV = $hc/\lambda \sim 12400$ eV-Å/λ. $\lambda = 12400$ Å/25000

Problem 16:
(C) We have constructive interference when the difference in optical path length (one way) is $\Delta = m\lambda/2$. Here $\Delta = nd - d = 40*\lambda/2$. $n - 1 = 40*500*10^{-9}/(2*0.05) = 0.0002$

Problem 17:
(B) density ~ $6*10^{23}$ molecules/ $22.4*10^{-3}\ \text{m}^3$.
Cross section ~ $8*10^{-20}\ \text{m}^2$ (πr^2 with r approximately 2 angstrom)
Mean free path ~ $(4*10^{-7})$ m.

Problem 18:
(E) $\Delta U = \Delta Q - \Delta W$, increase in internal energy of a system
= heat put into the system - work done by the system on its surroundings
$\Delta U = 0$, since we start and end at A, $\Delta Q = \Delta W$.
A → B: isothermal process, $\Delta W = \int_A^B PdV = \int_A^B (RT_h/V)dV = RT_h\ln(V_2/V_1)$
B → C: constant pressure,: $\Delta W = -P(V_2 - V_1) = -R(T_h - T_c)$
$\Delta Q = RT_h\ln(V_2/V_1) - R(T_h - T_c)$

Problem 19:
(B) Kinetic energy at large distances = potential energy at distance of closest approach.
5 MEV * $1.6*10^{-13}$ J/MeV = $9*10^9* 2*50*(1.6*10^{-19})^2/d$, d ~ $3*10^{-14}$ m.

Problem 20:
(D) In the CM frame the particle bounces back with the same speed it enters the collision. The CM frame therefore moves with speed 0.2v into the direction of the initial velocity of the particle. In the CM frame the particle of mass 4u moves with speed 0.8v and the atom of mass m moves with speed 0.2v. The magnitude of the momentum is the same for both. In the CM frame we have 4u*0.8v = m*0.2v. m = 16u.

Problem 21:
(D) $F_N = mg + mv^2/r$

Problem 22:
(A) The value of the work will be the same for all of the paths. The electric field is a conservative field.

Problem 23:
(D) $1/x_o + 1/x_i = 1/f$, $1/x_i = 1/6\text{cm} - 1/8\text{cm}$, $x_i = 24$ cm.

Problem 14:
(D) Conservation of angular momentum

Problem 25:

Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$. The light bends away from the normal in the diagram.