9707087896

Name: ____________________

1. 4 × 12 =	**2.** 6 × 9 =	**3.** 5 × 11 =	**4.** 3 × 10 =	**5.** 12 × 9 =
6. 8 × 5 =	**7.** 12 × 11 =	**8.** 5 × 6 =	**9.** 10 × 8 =	**10.** 3 × 3 =
11. 11 × 3 =	**12.** 4 × 11 =	**13.** 9 × 5 =	**14.** 9 × 6 =	**15.** 4 × 11 =
16. 5 × 6 =	**17.** 10 × 8 =	**18.** 12 × 3 =	**19.** 7 × 3 =	**20.** 11 × 6 =
21. 10 × 6 =	**22.** 9 × 9 =	**23.** 5 × 11 =	**24.** 12 × 3 =	**25.** 6 × 12 =
26. 3 × 4 =	**27.** 12 × 9 =	**28.** 7 × 9 =	**29.** 12 × 9 =	**30.** 7 × 5 =
31. 3 × 5 =	**32.** 11 × 3 =	**33.** 6 × 5 =	**34.** 3 × 4 =	**35.** 9 × 11 =
36. 8 × 5 =	**37.** 7 × 11 =	**38.** 3 × 7 =	**39.** 11 × 7 =	**40.** 6 × 11 =
41. 8 × 7 =	**42.** 3 × 8 =	**43.** 3 × 7 =	**44.** 5 × 3 =	**45.** 4 × 9 =
46. 6 × 4 =	**47.** 12 × 4 =	**48.** 4 × 5 =	**49.** 6 × 5 =	**50.** 7 × 12 =
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56. 8 × 5 =	**57.** 10 × 9 =	**58.** 11 × 10 =	**59.** 4 × 3 =	**60.** 11 × 5 =
61. 10 × 4 =	**62.** 7 × 9 =	**63.** 5 × 8 =	**64.** 12 × 9 =	**65.** 11 × 7 =
66. 9 × 11 =	**67.** 7 × 11 =	**68.** 7 × 6 =	**69.** 4 × 6 =	**70.** 3 × 11 =
71. 9 × 9 =	**72.** 4 × 7 =	**73.** 5 × 12 =	**74.** 4 × 7 =	**75.** 3 × 3 =
76. 9 × 10 =	**77.** 4 × 3 =	**78.** 7 × 7 =	**79.** 9 × 6 =	**80.** 3 × 7 =
81. 10 × 10 =	**82.** 6 × 5 =	**83.** 8 × 10 =	**84.** 4 × 8 =	**85.** 9 × 10 =
86. 5 × 10 =	**87.** 5 × 7 =	**88.** 10 × 6 =	**89.** 12 × 10 =	**90.** 7 × 8 =
91. 8 × 8 =	**92.** 9 × 12 =	**93.** 12 × 6 =	**94.** 5 × 3 =	**95.** 10 × 3 =
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101. 11 × 9 =	**102.** 7 × 3 =	**103.** 4 × 5 =	**104.** 7 × 3 =	**105.** 12 × 11 =
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111. 11 × 4 =	**112.** 8 × 4 =	**113.** 8 × 7 =	**114.** 12 × 9 =	**115.** 8 × 7 =
116. 6 × 6 =	**117.** 4 × 11 =	**118.** 6 × 6 =	**119.** 4 × 10 =	**120.** 6 × 3 =

resistivity: $\rho(T_2) = \rho(T_1)(1 + \alpha \Delta T)$

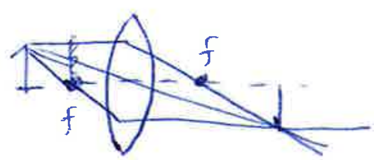
metals: $\alpha = (+)$
$\rho \uparrow$ $T \uparrow$
doping increases ρ

semi-conductors: $\alpha = (-)$
$\rho \downarrow$ $T \uparrow$
doping decreases ρ

conventional cell: contains more than 1 lattice pt.

primitive cell: contains 1 lattice pt. V_{cc} / # lattice pts cc $= V_{pc}$

Thin lenses: $d_i = \cancel{\frac{d_o f}{d_o - f}}$ $d_i = fd_o / f - d_o$ $M = h_i / h_o = -d_i / d_o$



ray diagrams: 1) through f, // other side
2) through center, continues along path
3) //, goes through f on other side.

Operators

$\hat{X} = x \qquad \hat{H} = -\frac{\hbar^2}{2m}\nabla^2 + V \qquad \hat{p} = -i\hbar\frac{\partial}{\partial x}$

Hermitian operators

- represent observables
  $\langle \hat{Q} \rangle = \langle \psi | \hat{Q} | \psi \rangle$ = real #
- conditions
  $\langle f | \hat{Q} g \rangle = \langle \hat{Q} f | g \rangle \implies \hat{a}^{+} = \hat{a}^{*} = \hat{a}$
- determinite states are eigenfxns of $\hat{Q}$.
- $\left(\frac{\partial}{\partial x}\right)^{+} = -\frac{\partial}{\partial x}$, note

doppler Effect

$f = f_0\left(\frac{V+V_s}{V+V_0}\right)$ $\qquad V_0 = \begin{cases} + \text{ away} \\ - \text{ move towards} \end{cases} \qquad V_s = \begin{cases} + \text{ towards} \\ - \text{ away} \end{cases}$

$\frac{\lambda}{\lambda_0} = \sqrt{\frac{1+\beta}{1-\beta}}$ $\quad \beta = \frac{v}{c}$ for relativistic dopplershift

$= \frac{f_0}{f}$

Harmonic oscillator Potential

$E_n = \hbar\omega(n + 1/2)$ $\quad$ n lowest = 0 $\quad \langle V \rangle = \langle T \rangle = \frac{1}{2}\hbar\omega\,(n + 1/2)$

$\omega = \sqrt{k/m} \qquad X = A\sin\omega t + B\cos\omega t$

$\psi_n \propto e^{-\frac{m\omega x^2}{2\hbar}} H_n(x)$

linear → rotational kinematics

$x \to \theta \qquad S_{arc} = r\theta \qquad \Delta X = v_0 t + 1/2\, a t^2 \to \Delta\theta = \omega_0 t + 1/2\,\alpha t^2$

$v \to \omega \qquad V_\perp = r \times \omega \qquad V = v_0 + at$

$a \to \alpha \qquad a_\perp = r \times \alpha \qquad V^2 = v_0^2 + 2a\Delta x$

$p \to L \qquad L = r \times p \qquad L = I\omega \quad (p = mv)$

$F \to \tau \qquad \tau = r \times F \qquad \tau = dL/dt \quad (F = \partial p/\partial t)$

$m \to I \qquad I \propto mr^2$

Lagrangian + Hamiltonian dynamics

$L = T - U \qquad H = T + U$ if $U \neq U(v)$, $\neq U(t)$ $\qquad$ EOMs:

$\frac{\partial L}{\partial q} - \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) = 0 \qquad p = \frac{\partial L}{\partial \dot{q}} \qquad \dot{q}_k = \frac{\partial H}{\partial p_k}$

↑EOMs $\qquad -\dot{p}_k = \frac{\partial H}{\partial q_k}$

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Name: ____________________

1. 130 ÷ 13 =	**2.** 120 ÷ 12 =	**3.** 27 ÷ 9 =	**4.** 195 ÷ 13 =	**5.** 98 ÷ 7 =
6. 35 ÷ 5 =	**7.** 56 ÷ 14 =	**8.** 50 ÷ 5 =	**9.** 75 ÷ 5 =	**10.** 140 ÷ 10 =
11. 169 ÷ 13 =	**12.** 42 ÷ 6 =	**13.** 77 ÷ 7 =	**14.** 40 ÷ 4 =	**15.** 6 ÷ 2 =
16. 182 ÷ 13 =	**17.** 165 ÷ 15 =	**18.** 56 ÷ 14 =	**19.** 140 ÷ 14 =	**20.** 120 ÷ 10 =
21. 88 ÷ 8 =	**22.** 75 ÷ 5 =	**23.** 130 ÷ 10 =	**24.** 196 ÷ 14 =	**25.** 90 ÷ 9 =
26. 156 ÷ 12 =	**27.** 117 ÷ 13 =	**28.** 77 ÷ 7 =	**29.** 120 ÷ 12 =	**30.** 135 ÷ 9 =
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41. 150 ÷ 10 =	**42.** 126 ÷ 14 =	**43.** 105 ÷ 7 =	**44.** 36 ÷ 12 =	**45.** 143 ÷ 11 =
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86. 44 ÷ 4 =	**87.** 99 ÷ 9 =	**88.** 45 ÷ 5 =	**89.** 65 ÷ 13 =	**90.** 156 ÷ 13 =
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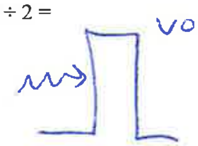
96. 72 ÷ 12 =	**97.** 48 ÷ 6 =	**98.** 10 ÷ 5 =	**99.** 20 ÷ 10 =	**100.** 150 ÷ 10 =
101. 210 ÷ 14 =	**102.** 165 ÷ 11 =	**103.** 27 ÷ 3 =	**104.** 150 ÷ 15 =	**105.** 77 ÷ 7 =
106. 104 ÷ 8 =	**107.** 112 ÷ 8 =	**108.** 72 ÷ 9 =	**109.** 132 ÷ 11 =	**110.** 180 ÷ 12 =
111. 16 ÷ 4 =	**112.** 39 ÷ 3 =	**113.** 120 ÷ 8 =	**114.** 40 ÷ 10 =	**115.** 196 ÷ 14 =
116. 100 ÷ 10 =	**117.** 36 ÷ 6 =	**118.** 60 ÷ 5 =	**119.** 35 ÷ 7 =	**120.** 26 ÷ 2 =

Transmission / refl / tunneling through barrier



incident: Ae^{ikx} refl: Re^{-ikx} Trans: Te^{ikx}

Limits: $V_0 \to 0$ $R \to 0$

$V_0 \to \infty$ $T \to 0$

Prb(Trans) = $|T/A|^2$

Prb(refl) = $|R/A|^2$

1 = Prb(T) + Prb(R)

tunneling depth $d \propto 1/\sqrt{V-E}$

Hydrogen spectral series

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \quad R = 1E7\ m^{-1}$$

Lyman, $n_f = 1$

Balmer, $n_f = 2$

Paschen, $n_f = 3$

largest $\lambda \leftrightarrow$ lowest E transition

$n_f + 1 = n_i$

$$\Delta E = E_0\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

hyperfine splitting

- spin/spin of e^-/nucleus
- responsible for 21cm line

$\mu_p = \frac{ge}{2m_p}\langle \bar{S}_p \rangle \qquad \mu_e = \frac{-e}{m_e}\langle \bar{S}_e \rangle$

$E'_{hf} = \frac{\mu_0 g_p e^2}{3\pi m_p m_e a^3}\langle \bar{S}_p \cdot \bar{S}_e \rangle \qquad E'_{hf} \propto \frac{e^2}{m_p m_e a^3}\langle \bar{S}_p \cdot \bar{S}_e \rangle$

Fine structure

- spin/orbit coupling & relativistic correction
  - breaks ℓ degeneracy, retains j degeneracy
  - why $E_{2S} < E_{2P}$

Zeeman Effect

- atom in external $\bar{B}$
- spin/B coupling +orbit ang. momentum

$H'_z = -(\bar{\mu}_e + \bar{\mu}_s)\cdot \bar{B}_{ext}$

- weak $B_{ext} \ll B_{int} \rightarrow E' = \mu_B g_j m_j B_{ext}$ breaks m_j degeneracy into $2j+1$ levels
- strong $B_{ext} \gg B_{int} \rightarrow E' = \mu_B B_{ext}(m_\ell + 2m_s)$

Stark Effect

- external E
- not spin dependent
- $H' = eE_z$ if $E = \hat{E}_z$
- hydrogen, $E'_1 = \langle H' \rangle = eE\int_0^\infty d^3r\, z|\psi_{100}|^2 = 0$ odd even

degenerate perturbation theory

- a state w/ n degenerate states breaks into n distinct E levels
- tensor, $W_{aa}, W_{bb}, W_{cc}, = E_a, E_b, E_c$ of unperturbed states

$$\begin{pmatrix} W_{aa} & W_{ab} \\ W_{ba} & W_{bb} \end{pmatrix} \Rightarrow W_{ab} = W_{ba}^*$$

Non degenerate PT

- $H = H' + H^0$
- 1st order: $E'_n = \langle \psi_n | H' | \psi_n \rangle = \langle H' \rangle$

$\psi'_n = \sum_{m,n} \frac{\langle \psi_m^0 | H' | \psi_n^0 \rangle}{E_n^0 - E_m^0}\psi_m^0$

- if $\bar{E}$ introduced
  $H' = eE \rightarrow E' = 0$
- potential raised by const
  $H' = V_0 \rightarrow E' = V_0$

Courtesy of MathScore.com

Name: ____________

1. 9 + 2 =	**2.** 9 + 5 =	**3.** 17 + 10 =	**4.** 4 + 12 =	**5.** 16 + 19 =
6. 7 + 18 =	**7.** 8 + 6 =	**8.** 8 + 19 =	**9.** 2 + 14 =	**10.** 8 + 3 =
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51. 13 + 6 =	**52.** 20 + 3 =	**53.** 11 + 15 =	**54.** 3 + 19 =	**55.** 16 + 13 =
56. 5 + 9 =	**57.** 16 + 17 =	**58.** 16 + 20 =	**59.** 3 + 2 =	**60.** 6 + 16 =
61. 13 + 2 =	**62.** 9 + 14 =	**63.** 2 + 15 =	**64.** 2 + 7 =	**65.** 4 + 18 =
66. 18 + 15 =	**67.** 4 + 18 =	**68.** 16 + 14 =	**69.** 12 + 17 =	**70.** 13 + 7 =
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86. 17 + 3 =	**87.** 11 + 10 =	**88.** 11 + 15 =	**89.** 4 + 2 =	**90.** 4 + 12 =
91. 8 + 18 =	**92.** 2 + 17 =	**93.** 15 + 15 =	**94.** 10 + 9 =	**95.** 8 + 16 =
96. 6 + 17 =	**97.** 18 + 15 =	**98.** 17 + 17 =	**99.** 17 + 5 =	**100.** 4 + 13 =
101. 6 + 14 =	**102.** 2 + 16 =	**103.** 8 + 5 =	**104.** 16 + 10 =	**105.** 15 + 19 =
106. 2 + 2 =	**107.** 17 + 2 =	**108.** 18 + 11 =	**109.** 16 + 7 =	**110.** 18 + 3 =
111. 3 + 3 =	**112.** 19 + 20 =	**113.** 16 + 15 =	**114.** 16 + 12 =	**115.** 19 + 18 =
116. 5 + 4 =	**117.** 12 + 6 =	**118.** 18 + 18 =	**119.** 9 + 14 =	**120.** 8 + 3 =

Particle in a Box - Infinite Sq. well $\quad \psi = 0$ @ walls

$$E_n = n^2 E_0 \quad E_0 = \frac{\hbar^2 k_0^2}{2m} = \frac{p_0^2}{2m} \quad k_n = \frac{n\pi}{a} \quad p_n = \hbar k_n \quad \psi = \sqrt{\frac{2}{a}} \sin(k_n x)$$

3-D, $E = \frac{\hbar^2}{2m}\left[k_x^2 + k_y^2 + k_z^2\right]$

Schrö : $\left(\frac{-\hbar^2}{2m}\nabla^2 + V\right)\psi = i\hbar \frac{\partial \psi}{\partial t}$

separable solns: $\psi = \phi(t)\,\psi(x)$

$$\phi(t) = e^{-iE_n t/\hbar}$$

Free particle $\quad \psi = Ae^{i(kx - \omega t)}$ $\quad$ wave packet solns, $\quad \psi = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} \phi(k) e^{ikx}\, dk$

packet moves at group velocity, $V_g = \frac{\partial \omega}{\partial k}$ $\quad \phi = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} \psi(x) e^{-ikx}\, dx$

$\Delta x \Delta k \sim 1$

$\Delta x \Delta p \sim \hbar \quad p = \hbar k$

index of refraction:

$n = \frac{c}{v}$ $\quad v = v_\varphi = \frac{\omega}{k} = \sqrt{1/\varepsilon\mu}$

$\lambda = \frac{\lambda_0}{n}$ inside a medium

$n = \frac{c}{v} = \sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}}$

Gauss' Laws

$\int E \cdot da = \frac{Q_{in}}{\varepsilon_0}$ $\quad \nabla \cdot E = \frac{\rho_{in}}{\varepsilon_0}$

$\int B \cdot dl = \mu_0 I_{encl}$ (Amp) $\longrightarrow$ $\int B \cdot da = 0$ $\quad \nabla \cdot B = 0$

$\int g \cdot da = -4\pi M G$ $\quad \nabla \cdot g = -4\pi G \rho$

damped-driven oscillator

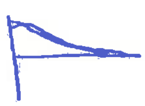
$F = -kx - b\dot{x} + A\cos\theta$ driven $\quad \omega_0 = \sqrt{k/m}$

hookes $\quad$ damping $\propto v$ $\quad \beta = b/2m$

underdamped: $\omega_0 > \beta$

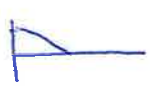
$x_u = Ae^{-\beta t}\cos(\omega' t + \phi)$ $\quad \omega' = \sqrt{\omega_0^2 - \beta^2}$

overdamped: $\omega_0 < \beta$



$x_o = Ae^{-\beta t} e^{-\omega'' t}$ $\quad \omega'' = \sqrt{\beta^2 - \omega_0^2}$

critically damped: $\omega_0 = \beta$



$x_c = A_1 e^{-\omega_0 t} + A_2 t e^{-\omega_0 t}$

Name: ____________________

1. 23 - 7 =	**2.** 30 - 10 =	**3.** 29 - 17 =	**4.** 28 - 19 =	**5.** 23 - 11 =
6. 22 - 12 =	**7.** 35 - 19 =	**8.** 16 - 8 =	**9.** 28 - 19 =	**10.** 26 - 16 =
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21. 27 - 8 =	**22.** 15 - 13 =	**23.** 18 - 13 =	**24.** 27 - 8 =	**25.** 8 - 1 =
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116. 11 - 7 =	**117.** 26 - 13 =	**118.** 10 - 2 =	**119.** 15 - 14 =	**120.** 20 - 13 =

Travelling wave formalism: $\frac{\partial^2\psi}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2\psi}{\partial t^2}$ $v = \sqrt{\frac{\text{restoring force}}{\text{density}}}$

$v_\phi = \frac{\omega}{k}$ $\psi = A\cos k(vt - x) = A\cos(\omega t - kx)$

in 1 period $x - vT = 2\pi$

Maxwell velocity distribution: speeds of molecules in ideal gas

$D(v) \propto v^2 e^{-E/k_BT}$

mean free path: $\ell = \frac{1}{n\sigma}$ $n = \frac{\text{particles}}{\text{vol}}$ σ = scatt cross section

particle diffusion: Fick's Law $J_p = -D\nabla n$ particle density   constant

Thermal diffusion: Fourier's Law $J_q = \Phi_q = -\kappa\nabla T$ conductivity (thermal)

Type of interaction	quantity exch.	var.	Formula
mechanical	volume	P	$P = -\left(\frac{\partial U}{\partial V}\right)_{S,N} = T\left(\frac{\partial S}{\partial V}\right)_{U,N}$
thermal	temp/energy	T	$T = \left(\frac{\partial U}{\partial S}\right)_{V,N}$
diffusive	particles	μ	$\mu = \left(\frac{\partial U}{\partial N}\right) = T\left(\frac{\partial S}{\partial N}\right)$

Thermo identity: $dU = TdS - PdV + \mu dN$

heat capacity: $\boxed{C \equiv \frac{dQ}{dT}}$

$C_P = \left(\frac{dQ}{dT}\right)_P = T\left(\frac{\partial S}{\partial T}\right)$ $\quad C_V = \left(\frac{\partial Q}{\partial T}\right)_V = \left(\frac{\partial U}{\partial T}\right)_V$ total E

$C_P > C_V$ since @const P the system looses E in the form of work $\Rightarrow$ for the same Q $dT_P < dT_V$, thus $C_P > C_V$

Fourier's Law: heat flux

$\phi_q = -k \nabla T$ $\quad k =$ thermal conductivity units $= \frac{W}{m \cdot K}$

flo of energy / time·area
units $= W/m^2$

water density
$1\,K = 1\,kg$ $\quad \rho = 1\,g/cm^3$

decay modes

${}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$ $\quad {}^{0}_{1}\beta + {}^{0}_{0}\nu$

${}^{4}_{2}\alpha$ $\quad {}^{2}_{1}D$

${}^{0}_{0}\gamma$

Notation $\quad {}^{A}_{Z}X$

A: mass # $= p^+ + n^0$

Z: ~~mass #~~ # p^+ = chemical #

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1. 3 × 11 =	**2.** 3 × 8 =	**3.** 6 × 5 =	**4.** 4 × 6 =	**5.** 7 × 7 =
6. 5 × 10 =	**7.** 4 × 9 =	**8.** 8 × 5 =	**9.** 12 × 9 =	**10.** 12 × 5 =
11. 12 × 11 =	**12.** 8 × 6 =	**13.** 10 × 6 =	**14.** 8 × 6 =	**15.** 6 × 6 =
16. 7 × 7 =	**17.** 4 × 7 =	**18.** 12 × 8 =	**19.** 10 × 4 =	**20.** 11 × 5 =
21. 8 × 4 =	**22.** 12 × 10 =	**23.** 10 × 7 =	**24.** 3 × 9 =	**25.** 3 × 12 =
26. 12 × 3 =	**27.** 10 × 8 =	**28.** 6 × 7 =	**29.** 12 × 12 =	**30.** 11 × 5 =
31. 6 × 5 =	**32.** 10 × 8 =	**33.** 10 × 10 =	**34.** 3 × 7 =	**35.** 11 × 12 =
36. 10 × 7 =	**37.** 4 × 9 =	**38.** 4 × 11 =	**39.** 3 × 4 =	**40.** 8 × 4 =
41. 4 × 7 =	**42.** 4 × 11 =	**43.** 12 × 8 =	**44.** 6 × 12 =	**45.** 8 × 5 =
46. 4 × 11 =	**47.** 7 × 12 =	**48.** 7 × 5 =	**49.** 10 × 8 =	**50.** 7 × 7 =
51. 3 × 8 =	**52.** 3 × 4 =	**53.** 7 × 4 =	**54.** 6 × 12 =	**55.** 6 × 7 =
56. 7 × 8 =	**57.** 6 × 7 =	**58.** 4 × 10 =	**59.** 6 × 9 =	**60.** 12 × 8 =
61. 8 × 7 =	**62.** 8 × 12 =	**63.** 9 × 5 =	**64.** 7 × 6 =	**65.** 11 × 12 =
66. 10 × 11 =	**67.** 8 × 11 =	**68.** 12 × 12 =	**69.** 3 × 6 =	**70.** 12 × 6 =
71. 11 × 7 =	**72.** 11 × 4 =	**73.** 12 × 3 =	**74.** 11 × 5 =	**75.** 9 × 11 =
76. 11 × 5 =	**77.** 5 × 6 =	**78.** 5 × 11 =	**79.** 9 × 10 =	**80.** 4 × 7 =
81. 9 × 12 =	**82.** 5 × 4 =	**83.** 11 × 5 =	**84.** 4 × 11 =	**85.** 9 × 4 =
86. 5 × 7 =	**87.** 9 × 4 =	**88.** 9 × 8 =	**89.** 4 × 8 =	**90.** 11 × 11 =
91. 6 × 10 =	**92.** 3 × 8 =	**93.** 4 × 5 =	**94.** 6 × 10 =	**95.** 12 × 8 =
96. 4 × 9 =	**97.** 8 × 7 =	**98.** 11 × 7 =	**99.** 10 × 12 =	**100.** 6 × 6 =
101. 4 × 8 =	**102.** 10 × 10 =	**103.** 10 × 6 =	**104.** 6 × 11 =	**105.** 12 × 4 =
106. 10 × 5 =	**107.** 11 × 10 =	**108.** 11 × 12 =	**109.** 3 × 4 =	**110.** 9 × 12 =
111. 10 × 11 =	**112.** 9 × 6 =	**113.** 6 × 7 =	**114.** 10 × 3 =	**115.** 7 × 3 =
116. 6 × 8 =	**117.** 9 × 4 =	**118.** 6 × 6 =	**119.** 8 × 9 =	**120.** 5 × 7 =

Beats: $f_b = f_1 - f_2$ $T_b = \frac{1}{f_1 - f_2}$ beats occur when freqs f_1 & f_2 are close together.

$f_2 = n f_0$ ← the tuned frequency
↑ harmonic

1st Law of Thermo: $\Delta U = Q + W$

2nd Law: E flows spontaneously ~~to increase~~ until the system is at the most likely macrostate. ⇒ Entropy tends to increase

3rd Law: $S(T=0)=1$ so $C_V \to 0$ as $T \to 0$

Fundamental assumption of stat mech: all accessible microstates are equally likely

irreversible process: creates new entropy

reversible process: creates no new entropy.

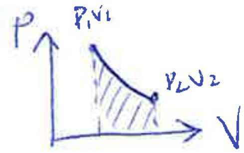
Isothermal compression: slow

$P_1V_1 = P_2V_2$

$W = NkT\ln(V_i/V_f)$, $W = -\int_{V_i}^{V_f} P\,dV$

$\Delta U = 0$ since $\Delta T = 0$, $\Delta U = \frac{f}{2}NK\Delta T$

$\Rightarrow Q = -W$



W = area under curve.

Adiabatic Compression: fast

no heat flows, $\Delta Q = 0 \rightarrow \Delta U = W$

equipartion, $\Delta U = NK\Delta T = W$

$V_f T_f^{f/2} = V_i T_i^{f/2}$ $\quad f = \text{dof}$

$V_f^{\gamma} P_F = V_i^{\gamma} P_F$ $\quad \gamma = \frac{f+2}{f}$

adiabat connects btwn 2 isotherms

$W = \frac{P_fV_f - P_iV_i}{1-\gamma}$

↳ derive: $PV^{\gamma} = C \rightarrow P = C/V^{\gamma}$

$W = \int P\,dV = \int C\frac{dV}{V^{\gamma}} = \frac{1}{\gamma}\frac{C}{V^{\gamma-1}}\Big|_{V_1}^{V_2}$

Heat

$Q = Tds$ $\quad U = Q + W$

$Q = mc\Delta T$

$Q = Pt$

↑ power

cyclotron

$\omega = \frac{qB}{m}$ $\quad F_c = F_B \rightarrow \frac{mv^2}{r} = qvB$ $\quad V = \frac{qBr}{m} = r\omega$

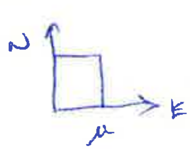
$\omega = \frac{qB}{m}$

Fermi:

$E_F = k_B T_F$ $\quad p_F = \hbar k_F \rightarrow E_F = \frac{p^2}{2m} = \frac{\hbar^2 k^2}{2m}$ $\quad v_F = \frac{p_F}{m}$

$k_F = \left(\frac{3\pi^2 N}{Vol}\right)^{1/3}$ $\quad P_F = \frac{2}{3}\frac{E_F}{V}$

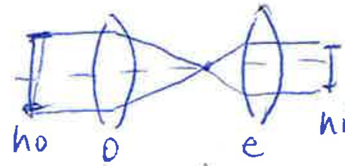
degenerate Fermi gas: so cold that nearly all states below E_F are occupied + above unoccupied



Telescope + Magnification

: 2 lenses share a common focal point

$M = \cancel{\frac{do}{de}}$ $\quad M = -\frac{f_o}{f_e} = \frac{\theta_{eye}}{\theta_{object}}$ $\quad d_o + d_e = f_o + f_e$



$h_o > h_i$

$f_o > f_e$

Courtesy of MathScore.com

Name: ________________

1. 20 ÷ 4 =	**2.** 44 ÷ 4 =	**3.** 0 ÷ 1 =	**4.** 70 ÷ 10 =	**5.** 33 ÷ 3 =
6. 90 ÷ 10 =	**7.** 12 ÷ 3 =	**8.** 44 ÷ 4 =	**9.** 25 ÷ 5 =	**10.** 10 ÷ 2 =
11. 8 ÷ 1 =	**12.** 7 ÷ 7 =	**13.** 55 ÷ 11 =	**14.** 1 ÷ 1 =	**15.** 88 ÷ 8 =
16. 7 ÷ 7 =	**17.** 9 ÷ 9 =	**18.** 11 ÷ 1 =	**19.** 18 ÷ 2 =	**20.** 40 ÷ 10 =
21. 30 ÷ 5 =	**22.** 40 ÷ 10 =	**23.** 44 ÷ 11 =	**24.** 63 ÷ 7 =	**25.** 20 ÷ 4 =
26. 32 ÷ 4 =	**27.** 18 ÷ 2 =	**28.** 0 ÷ 6 =	**29.** 4 ÷ 4 =	**30.** 44 ÷ 4 =
31. 6 ÷ 1 =	**32.** 60 ÷ 10 =	**33.** 80 ÷ 8 =	**34.** 11 ÷ 1 =	**35.** 2 ÷ 2 =
36. 22 ÷ 11 =	**37.** 0 ÷ 10 =	**38.** 20 ÷ 10 =	**39.** 36 ÷ 6 =	**40.** 0 ÷ 6 =
41. 1 ÷ 1 =	**42.** 6 ÷ 6 =	**43.** 63 ÷ 7 =	**44.** 24 ÷ 4 =	**45.** 80 ÷ 8 =
46. 11 ÷ 11 =	**47.** 15 ÷ 3 =	**48.** 8 ÷ 4 =	**49.** 60 ÷ 6 =	**50.** 4 ÷ 4 =
51. 5 ÷ 5 =	**52.** 60 ÷ 10 =	**53.** 21 ÷ 3 =	**54.** 0 ÷ 2 =	**55.** 0 ÷ 10 =
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66. 30 ÷ 6 =	**67.** 72 ÷ 9 =	**68.** 8 ÷ 8 =	**69.** 16 ÷ 2 =	**70.** 5 ÷ 5 =
71. 6 ÷ 3 =	**72.** 8 ÷ 8 =	**73.** 30 ÷ 6 =	**74.** 3 ÷ 3 =	**75.** 7 ÷ 7 =
76. 0 ÷ 2 =	**77.** 35 ÷ 5 =	**78.** 11 ÷ 1 =	**79.** 0 ÷ 2 =	**80.** 40 ÷ 10 =
81. 6 ÷ 2 =	**82.** 5 ÷ 5 =	**83.** 27 ÷ 9 =	**84.** 11 ÷ 11 =	**85.** 6 ÷ 1 =
86. 60 ÷ 6 =	**87.** 30 ÷ 10 =	**88.** 54 ÷ 6 =	**89.** 18 ÷ 3 =	**90.** 6 ÷ 1 =
91. 10 ÷ 10 =	**92.** 20 ÷ 4 =	**93.** 90 ÷ 9 =	**94.** 11 ÷ 1 =	**95.** 0 ÷ 3 =
96. 5 ÷ 1 =	**97.** 36 ÷ 6 =	**98.** 28 ÷ 4 =	**99.** 14 ÷ 2 =	**100.** 35 ÷ 5 =
101. 9 ÷ 9 =	**102.** 9 ÷ 3 =	**103.** 12 ÷ 4 =	**104.** 40 ÷ 4 =	**105.** 18 ÷ 2 =
106. 2 ÷ 2 =	**107.** 12 ÷ 3 =	**108.** 40 ÷ 5 =	**109.** 4 ÷ 4 =	**110.** 14 ÷ 7 =
111. 27 ÷ 3 =	**112.** 21 ÷ 3 =	**113.** 42 ÷ 6 =	**114.** 21 ÷ 3 =	**115.** 25 ÷ 5 =
116. 3 ÷ 3 =	**117.** 64 ÷ 8 =	**118.** 0 ÷ 3 =	**119.** 80 ÷ 10 =	**120.** 25 ÷ 5 =

[illegible] multiplicity / states: $Prb(\Omega n) = \Omega(n) / \Omega(all)$

Ω = multiplicity = how many different microstates yield a macrostate

tot # microstates = (# states thing can be in)$^{(\text{\# of things})}$

example 3 coins, $2^{\cancel{8}3} = 8 = \Omega$ ← 3 coins

↑ heads or tails

# of ways to choose n things from N: $\Omega\binom{N}{n} = \dfrac{N!}{(N-n)!\,n!}$

Rocket Motion

$$u\frac{dm}{dt} + M\frac{dV}{dt} = 0$$

$$V_f = V_0 + u\ln\left(\frac{M_i}{M_f}\right)$$

Collisions

1. momentum + mass always consv. classically
2. use p equality for before/after coll. even if elastic
3. elasic → consv. of KE

$$\varepsilon = 1 = \frac{|V_1| + |V_2|}{|u_1| + |u_2|} \begin{matrix} \leftarrow \text{fin} \\ \leftarrow \text{before} \end{matrix}$$

** don't forget to include (−) + (+) to direction of velocity in momentum eqns!

4. only use KE for consv. of total E either before or after the collision
5. Impulse $I = F\Delta t = \Delta p = \Delta L$
6. cross section

$$N_{scat} = \frac{N_{target}}{\text{area}} N_{incident}\,\sigma$$

Springs / SHO

$F = -kx \Rightarrow U = \frac{1}{2}kx^2$ $\qquad \omega = \sqrt{k/m}$

$ma = -kx$

$\ddot{x} = -\omega_0^2 x = -k/m \cdot x$

solns: sins/cos

A = max amplitude

$E_{tot} = 1/2\,kA^2$

$KE = 1/2\,kA^2\cos^2(\omega_0 t)$

$PE = 1/2\,kA^2\sin^2(\omega_0 t)$

To find oscillations about the minimum of E in an arbitrary U

1. find equil. value $\frac{\partial U}{\partial x} = 0 \rightarrow x_0 = ?$
2. 2nd deriv. of taylor gives $\omega_0 \rightarrow 1/2\,V''(x_0) = 1/2\,m\omega^2$

degeneracy pressure of a solid: $P = \frac{3}{2}\frac{E}{V}$: The stabilizing internal pressure of that comes from the anti-symmeterization requirement for the wave fxns of identical fermions.

Courtesy of MathScore.com

Name: ____________

1. 6 + 17 =	**2.** 13 + 10 =	**3.** 15 + 9 =	**4.** 7 + 12 =	**5.** 16 + 3 =
6. 6 + 13 =	**7.** 19 + 18 =	**8.** 15 + 4 =	**9.** 13 + 8 =	**10.** 14 + 3 =
11. 7 + 6 =	**12.** 8 + 7 =	**13.** 8 + 19 =	**14.** 16 + 15 =	**15.** 6 + 13 =
16. 3 + 10 =	**17.** 10 + 14 =	**18.** 17 + 5 =	**19.** 3 + 4 =	**20.** 15 + 17 =
21. 5 + 19 =	**22.** 11 + 4 =	**23.** 17 + 6 =	**24.** 6 + 11 =	**25.** 12 + 17 =
26. 11 + 17 =	**27.** 3 + 17 =	**28.** 4 + 9 =	**29.** 17 + 18 =	**30.** 4 + 3 =
31. 11 + 5 =	**32.** 10 + 18 =	**33.** 16 + 7 =	**34.** 4 + 17 =	**35.** 9 + 17 =
36. 15 + 11 =	**37.** 16 + 6 =	**38.** 13 + 14 =	**39.** 10 + 16 =	**40.** 6 + 3 =
41. 13 + 15 =	**42.** 17 + 14 =	**43.** 13 + 18 =	**44.** 3 + 10 =	**45.** 16 + 5 =
46. 10 + 8 =	**47.** 7 + 18 =	**48.** 6 + 4 =	**49.** 5 + 8 =	**50.** 18 + 12 =
51. 5 + 14 =	**52.** 4 + 18 =	**53.** 17 + 14 =	**54.** 13 + 8 =	**55.** 10 + 16 =
56. 8 + 4 =	**57.** 11 + 6 =	**58.** 16 + 4 =	**59.** 5 + 16 =	**60.** 12 + 19 =
61. 19 + 19 =	**62.** 7 + 6 =	**63.** 18 + 10 =	**64.** 7 + 4 =	**65.** 15 + 6 =
66. 13 + 18 =	**67.** 17 + 14 =	**68.** 16 + 15 =	**69.** 9 + 9 =	**70.** 4 + 16 =
71. 6 + 9 =	**72.** 18 + 14 =	**73.** 13 + 14 =	**74.** 16 + 15 =	**75.** 11 + 8 =
76. 14 + 10 =	**77.** 8 + 19 =	**78.** 14 + 6 =	**79.** 10 + 19 =	**80.** 7 + 6 =
81. 6 + 18 =	**82.** 4 + 4 =	**83.** 13 + 18 =	**84.** 16 + 19 =	**85.** 7 + 17 =
86. 16 + 11 =	**87.** 7 + 14 =	**88.** 5 + 18 =	**89.** 9 + 19 =	**90.** 13 + 18 =
91. 7 + 8 =	**92.** 9 + 13 =	**93.** 7 + 3 =	**94.** 17 + 15 =	**95.** 3 + 5 =
96. 18 + 6 =	**97.** 3 + 19 =	**98.** 7 + 13 =	**99.** 17 + 4 =	**100.** 13 + 5 =
101. 19 + 9 =	**102.** 13 + 7 =	**103.** 4 + 16 =	**104.** 5 + 11 =	**105.** 15 + 16 =
106. 9 + 3 =	**107.** 5 + 16 =	**108.** 13 + 10 =	**109.** 17 + 11 =	**110.** 5 + 17 =
111. 13 + 3 =	**112.** 4 + 14 =	**113.** 3 + 9 =	**114.** 8 + 17 =	**115.** 10 + 18 =
116. 19 + 10 =	**117.** 8 + 13 =	**118.** 15 + 9 =	**119.** 9 + 18 =	**120.** 18 + 5 =

*** n = odd #s only

Thin films: $\Delta\phi = \begin{cases} 0 & n_2 < n_1 \\ \pi & n_2 > n_1 \end{cases}$ eqn for const. interf. $2d = \begin{cases} n\lambda/2, & \Delta\phi_{tot} = \pi \\ n\lambda, & \Delta\phi_{tot} = 0, 2\pi \end{cases}$

~~Ohm's~~ conductivity / current density

ohm's: $J = nq\bar{v}$

$J = \frac{ne^2\tau}{m} E = \sigma E$ $\qquad \sigma = \frac{ne^2\tau}{m}$

Resistance: $R = \frac{\rho L}{A} = \frac{L}{\sigma A}$

Boltzmann statistics: $Z = \sum_i g_i e^{-E_i/kT}$ $\quad g_i$ = degeneracy of i

$P(s) = \frac{g_s e^{-E_s/kT}}{Z}$ $\qquad P(A)/P(B) = \frac{g_A}{g_B} e^{(-A+B)/kT}$

$\langle \bar{X} \rangle = \frac{1}{Z} \sum_s X_s e^{-E_s/kT}$ avg of any value $\qquad \langle E \rangle = \frac{1}{Z} \sum_i E_i e^{-E_i/kT}$

$U = N\bar{E}$ total energy of the system.

Density of state distributions

fermions: $N_i = g_i / [e^{(E_i-\mu)/kT} + 1]$ $\qquad$ M/B: $N_i = g_i / [e^{[E_i-\mu]/kT} - 1]$ $\qquad$ Boltz: $N_i = g e^{-(E_i-\mu)/kT}$

Band pass

$\omega_0 \rightarrow \omega_0 L = \frac{1}{\omega_0 C} \rightarrow$ ~~ω_0~~ $\omega_0 = \frac{1}{\sqrt{LC}}$

Resonant frequency:

match C + L impedances → since they're inverse, will not matter if they're parallel or series.

$-||-\text{ell}-$ $\omega_0 = 1/\sqrt{LC}$

~~ω_0~~ $\omega_0 = \frac{1}{\sqrt{LC}}$

Central Force Motion

$\mu = \frac{m_1 m_2}{m_1 + m_2}$ $\quad R_{cm} = \frac{\sum_i m_i r_i}{\sum m_i}$ $\quad T = \frac{1}{2}\mu|\dot{r}|^2$ just plug in altered quantities.

$\bar{r}_1 = \frac{m_2}{m_1 + m_2}\bar{r}$ $\quad \bar{r}_2 = \frac{m_1}{m_1 + m_2}\bar{r}$ $\quad \bar{r} = \bar{r}_1 - \bar{r}_2$

Potential + E

$$E = \int \frac{k\,dq}{r^2} = k\int \frac{\sigma\,dA}{r^2} = k\int \frac{\rho\,dv}{r^2} = k\int \frac{\lambda\,dl}{r^2}$$

$$V = \int \frac{k\,dq}{r}$$

example ring of charge

$\sin\theta = \frac{z}{r} = \frac{E_z}{E}$

$E = k\int \frac{dQ}{r^2}$ $\quad r^2 = R^2 + z^2$

$dq = \lambda\,dl = Q$

$\hat{E} = \frac{kQ}{R^2 + z^2}$ $\quad$ but $E = \hat{E}_z$

$E = \frac{kQ}{R^2 + z^2}\sin\theta = \frac{kQ}{(R^2 + z^2)}\frac{z}{r} = \frac{kQz}{}$

Moments of Inertia

$I = cMR^2$

$I_{hoop} = MR^2$

$I_{disk} = \frac{1}{2}MR^2$

$I_{sphere\ hollow} = \frac{2}{3}MR^2$

$I_{sphere\ whole} = \frac{2}{5}MR^2$

$I_{point\ mass} = MR^2$

$I_{rod\ end} = \frac{1}{3}ML^2$

$I_{rod\ center} = \frac{1}{12}ML^2$

$L_{rot} = I\omega$

$T_{rot} = \frac{1}{2}I\omega^2$

$\tau = I\alpha = \frac{dL}{dt}$

$I_{parallel\ axis} = I_{cm} + MR^2_{displ}$

Courtesy of MathScore.com

Name: ____________

1. 27 - 16 =	**2.** 27 - 8 =	**3.** 21 - 6 =	**4.** 7 - 5 =	**5.** 21 - 17 =
6. 24 - 18 =	**7.** 19 - 5 =	**8.** 25 - 15 =	**9.** 28 - 12 =	**10.** 7 - 6 =
11. 23 - 6 =	**12.** 29 - 12 =	**13.** 30 - 16 =	**14.** 24 - 7 =	**15.** 23 - 17 =
16. 29 - 13 =	**17.** 22 - 8 =	**18.** 21 - 4 =	**19.** 20 - 5 =	**20.** 17 - 2 =
21. 11 - 2 =	**22.** 24 - 5 =	**23.** 20 - 8 =	**24.** 14 - 11 =	**25.** 28 - 10 =
26. 32 - 19 =	**27.** 29 - 18 =	**28.** 10 - 7 =	**29.** 14 - 10 =	**30.** 16 - 9 =
31. 18 - 3 =	**32.** 31 - 15 =	**33.** 26 - 7 =	**34.** 5 - 1 =	**35.** 22 - 15 =
36. 27 - 19 =	**37.** 19 - 11 =	**38.** 26 - 11 =	**39.** 30 - 18 =	**40.** 26 - 10 =
41. 23 - 6 =	**42.** 22 - 14 =	**43.** 20 - 6 =	**44.** 12 - 1 =	**45.** 19 - 2 =
46. 18 - 12 =	**47.** 36 - 19 =	**48.** 17 - 10 =	**49.** 30 - 15 =	**50.** 21 - 12 =
51. 30 - 18 =	**52.** 25 - 18 =	**53.** 9 - 3 =	**54.** 33 - 19 =	**55.** 28 - 14 =
56. 19 - 18 =	**57.** 19 - 3 =	**58.** 30 - 15 =	**59.** 34 - 16 =	**60.** 24 - 13 =
61. 35 - 17 =	**62.** 29 - 14 =	**63.** 11 - 5 =	**64.** 6 - 4 =	**65.** 21 - 8 =
66. 33 - 14 =	**67.** 27 - 12 =	**68.** 26 - 14 =	**69.** 15 - 14 =	**70.** 20 - 15 =
71. 7 - 1 =	**72.** 16 - 5 =	**73.** 22 - 19 =	**74.** 24 - 16 =	**75.** 17 - 3 =
76. 21 - 12 =	**77.** 20 - 8 =	**78.** 19 - 10 =	**79.** 38 - 19 =	**80.** 20 - 5 =
81. 18 - 15 =	**82.** 18 - 3 =	**83.** 18 - 16 =	**84.** 20 - 11 =	**85.** 24 - 12 =
86. 24 - 16 =	**87.** 13 - 4 =	**88.** 34 - 18 =	**89.** 2 - 1 =	**90.** 21 - 9 =
91. 28 - 9 =	**92.** 18 - 5 =	**93.** 31 - 18 =	**94.** 15 - 11 =	**95.** 31 - 16 =
96. 21 - 3 =	**97.** 23 - 13 =	**98.** 31 - 12 =	**99.** 27 - 16 =	**100.** 16 - 8 =
101. 20 - 11 =	**102.** 26 - 19 =	**103.** 5 - 2 =	**104.** 17 - 15 =	**105.** 15 - 4 =
106. 16 - 6 =	**107.** 19 - 10 =	**108.** 25 - 7 =	**109.** 24 - 9 =	**110.** 20 - 18 =
111. 20 - 1 =	**112.** 13 - 12 =	**113.** 20 - 16 =	**114.** 23 - 7 =	**115.** 6 - 1 =
116. 17 - 16 =	**117.** 14 - 9 =	**118.** 24 - 10 =	**119.** 14 - 10 =	**120.** 28 - 12 =

Blackbody radiation: Wien's Law: $T \cdot \lambda_{max} = 3\,mmK$ - det star temp.

Stephan-Boltzman: $P \propto AT^4$ ← use for photons coming through a hole in a box.

heat engines: $e \leq 1 - \frac{T_c}{T_h}$ $e = \frac{benefit}{cost} = \frac{W}{Q_h}$ $W = Q_h - Q_{out}$

refrigerators: $e \leq \frac{T_c}{T_h - T_c}$ $W = Q_h - Q_c$ $\Delta S = 0$, indep of working subs.

Onnes: superconductivity in Hg

Anderson: positron

Yukawa: strong nuclear

Fermi: 1st nuclear reactor

Mann + Zweig: quarks

Rontengen: X-rays

Penzias + Wilson: background radiation

Huygens: wave fronts

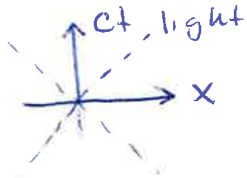
Cavendish: G

Oersted: connection b/wn E/M

Ampere: B force Law

Hertz: showed E/M waves existed

space-time diagram



$\Delta s > 0$ spacelike

- ordering of events is depends on reference frame
- there exists a ref frame where 2 events occur simultaneously, but they can't occur at same pt. in space.

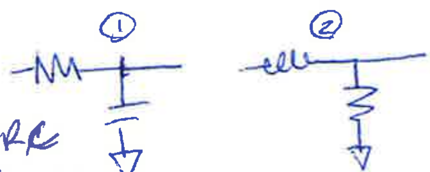
$\Delta s^2 = \Delta x^2 - (ct)^2$

$\Delta s^2 = \Delta x^2 - (ct)^2$

$\Delta s < 0$ timelike

- ordering of events is absolute
- Causal relationships are timelike
- two events can occur at same pt in space

low pass



$t = RC$
$f_c = 1/2\pi RC$

cuts out high frequencies - the corners of waves

"like a voltage divider"

- to calc transfer fxn

$T_1 = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1/j\omega C}{\frac{Rj\omega C + 1}{j\omega C}} = \frac{1}{1 + j\omega CR}$ $\quad \omega \to \infty$, $T_1 \to 0$ $\quad \omega \to 0$, $T_1 \to 1$

$T_2 = \frac{R}{j\omega L + R}$ $\quad \omega \to \infty$, $T_2 \to 0$ $\quad \omega \to 0$, $T_2 \to 1$

high pass

cuts out low frequencies.

$T_1 = \frac{R}{R + 1/j\omega C} = \frac{R}{\frac{j\omega CR + 1}{j\omega C}} = \frac{j\omega CR}{j\omega CR + 1}$ $\quad \omega \to 0$, $T_1 \to 0$ $\quad \omega \to \infty$, $T_1 \to 1$

$T_2 = \frac{j\omega L}{R + j\omega L}$ $\quad \omega \to 0$, $T_2 \to 0$ $\quad \omega \to \infty$, $T_2 \to 1$

Courtesy of MathScore.com

Name: ________________

1. 54 ÷ 9 =	**2.** 32 ÷ 4 =	**3.** 16 ÷ 4 =	**4.** 16 ÷ 2 =	**5.** 40 ÷ 8 =
6. 10 ÷ 10 =	**7.** 5 ÷ 1 =	**8.** 42 ÷ 7 =	**9.** 63 ÷ 9 =	**10.** 30 ÷ 10 =
11. 16 ÷ 2 =	**12.** 2 ÷ 1 =	**13.** 3 ÷ 3 =	**14.** 66 ÷ 11 =	**15.** 55 ÷ 5 =
16. 27 ÷ 9 =	**17.** 121 ÷ 11 =	**18.** 6 ÷ 1 =	**19.** 21 ÷ 7 =	**20.** 12 ÷ 2 =
21. 25 ÷ 5 =	**22.** 88 ÷ 8 =	**23.** 66 ÷ 6 =	**24.** 132 ÷ 12 =	**25.** 81 ÷ 9 =
26. 12 ÷ 2 =	**27.** 64 ÷ 8 =	**28.** 4 ÷ 1 =	**29.** 24 ÷ 4 =	**30.** 27 ÷ 3 =
31. 7 ÷ 7 =	**32.** 108 ÷ 9 =	**33.** 72 ÷ 12 =	**34.** 84 ÷ 7 =	**35.** 6 ÷ 6 =
36. 63 ÷ 9 =	**37.** 80 ÷ 8 =	**38.** 24 ÷ 3 =	**39.** 63 ÷ 9 =	**40.** 72 ÷ 8 =
41. 24 ÷ 2 =	**42.** 5 ÷ 1 =	**43.** 36 ÷ 9 =	**44.** 8 ÷ 4 =	**45.** 28 ÷ 7 =
46. 42 ÷ 7 =	**47.** 2 ÷ 2 =	**48.** 144 ÷ 12 =	**49.** 22 ÷ 2 =	**50.** 36 ÷ 12 =
51. 8 ÷ 8 =	**52.** 25 ÷ 5 =	**53.** 132 ÷ 12 =	**54.** 27 ÷ 3 =	**55.** 2 ÷ 2 =
56. 8 ÷ 2 =	**57.** 33 ÷ 3 =	**58.** 10 ÷ 1 =	**59.** 99 ÷ 9 =	**60.** 6 ÷ 6 =
61. 27 ÷ 3 =	**62.** 12 ÷ 4 =	**63.** 4 ÷ 2 =	**64.** 77 ÷ 11 =	**65.** 28 ÷ 4 =
66. 100 ÷ 10 =	**67.** 11 ÷ 11 =	**68.** 21 ÷ 3 =	**69.** 20 ÷ 10 =	**70.** 8 ÷ 4 =
71. 2 ÷ 2 =	**72.** 36 ÷ 9 =	**73.** 16 ÷ 2 =	**74.** 48 ÷ 4 =	**75.** 30 ÷ 5 =
76. 3 ÷ 3 =	**77.** 40 ÷ 4 =	**78.** 6 ÷ 6 =	**79.** 48 ÷ 8 =	**80.** 36 ÷ 4 =
81. 21 ÷ 7 =	**82.** 12 ÷ 1 =	**83.** 55 ÷ 5 =	**84.** 28 ÷ 4 =	**85.** 12 ÷ 12 =
86. 5 ÷ 5 =	**87.** 40 ÷ 4 =	**88.** 120 ÷ 12 =	**89.** 1 ÷ 1 =	**90.** 56 ÷ 8 =
91. 108 ÷ 9 =	**92.** 28 ÷ 7 =	**93.** 66 ÷ 11 =	**94.** 72 ÷ 8 =	**95.** 2 ÷ 1 =
96. 55 ÷ 11 =	**97.** 32 ÷ 8 =	**98.** 24 ÷ 2 =	**99.** 40 ÷ 4 =	**100.** 9 ÷ 9 =
101. 24 ÷ 6 =	**102.** 48 ÷ 6 =	**103.** 72 ÷ 6 =	**104.** 24 ÷ 12 =	**105.** 81 ÷ 9 =
106. 18 ÷ 3 =	**107.** 36 ÷ 12 =	**108.** 45 ÷ 9 =	**109.** 11 ÷ 11 =	**110.** 32 ÷ 8 =
111. 36 ÷ 6 =	**112.** 8 ÷ 8 =	**113.** 24 ÷ 6 =	**114.** 9 ÷ 1 =	**115.** 11 ÷ 11 =
116. 66 ÷ 6 =	**117.** 9 ÷ 1 =	**118.** 64 ÷ 8 =	**119.** 5 ÷ 5 =	**120.** 4 ÷ 4 =

Relativity Especial

V/c	γ
.1	1.005
.25	1.033
.5	1.151
.75	1.55
.9	2.29

$x = \gamma(x' + vt')$

$t = \gamma\left(t' + \frac{vx}{c^2}\right)$

$u_x' = \dfrac{u_x + v}{1 + \frac{u_x v}{c^2}}$

$u_z' = \dfrac{u_z}{\left(1 + \frac{u_x v}{c^2}\right)\gamma}$

motion in $\hat{x}$

transform btwn "rest" + moving frame only!

~~proper~~ rest length + time

time dilation: $t' = \gamma t_0$

length contraction: $x' = x_0/\gamma$

invariant interval

$\Delta s^2 = \Delta x^2 - (ct)^2$ ← transform btwn 2 moving frames.

Energy: $E_{rel} = \gamma E_0$

$p = \gamma p = \gamma m v$

$E_{rel}^2 = E_0^2 + (pc)^2$

$E_{rel} \neq \dfrac{p_{rel}^2}{2m}$

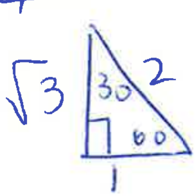
$p_x = \gamma\left(p_x' + \frac{v}{c^2} E'\right)$

$E = \gamma(E' + v p_x')$

invariant 4 vector

$p_y' = p_y$

30/60



Finite potential well

$E \propto n^2$

$d \propto 1/\sqrt{V-E_n}$ $\quad d = \hbar/\sqrt{2m(V-E_n)}$

$d \propto n$

fundamental particles

bosons - force carriers

guage bosons - gluon - strong

W, Z, - weak

photons - E/M

other - Higgs, graviton

fermions - associated with matter

quarks - up, down, top, bottom, strange, charm

leptons - electron, electron neutrino

muon, muon neutrino

tauon, tauon neutrino

Single slit diffraction

~~wen~~ $w\sin\theta = n\lambda$ $\quad \theta = \measuredangle$ btwn central max & ~~[illegible]~~ 1st min.

$\tan\theta = Y/L$

central maximum width

$\cancel{W} = \frac{2L\lambda}{d} = \Delta y_{max}$

diffraction grating

Fresnel diffraction

$d\sin\theta = n\lambda$ $\quad y = L\tan\theta = L\frac{\sin\theta}{\cos\theta} = \frac{Ln\lambda}{d\cos\theta}$

~~[illegible]~~

$N\uparrow, d\downarrow, y\uparrow$

double slit interference

$d\sin\theta = n\lambda$ const $\quad d\sin\theta = n(\lambda + \frac{\lambda}{2})$ dest.

$\Delta y = L\tan\theta$

Bragg $2d\sin\theta = n\lambda$ $\quad d = \frac{a}{\sqrt{h^2+k^2+\ell^2}}$ lattice spacing

miller indicies

~~E&M~~ Electrostatics ~~Eq.~~

$$\boxed{\nabla \cdot E = \frac{\rho_{in}}{\varepsilon_0} \qquad \nabla \times E = 0}$$

$F = \frac{k q_1 q_2}{r^2}$ $\qquad k = \frac{1}{4\pi\varepsilon_0}$ $\qquad k_{medium} = \frac{1}{4\pi\varepsilon}$ $\qquad \varepsilon = k\varepsilon_0$

$k = 9e9 \frac{Nm}{C^2}$

Classic E examples:

Sphere $\propto \frac{1}{r^2}$

infinite line $\propto \frac{1}{r}$

infinite plane doesn't fall off

$E_{plane} = \frac{\sigma}{2\varepsilon_0}\hat{n}$

ring of charge:

$E \propto \frac{x}{d^{3/2}} = \frac{x}{(x^2+R^2)^{3/2}}$

disk of charge

$E = \frac{\eta}{2\varepsilon_0}\left[1 - \frac{z}{(z^2+R^2)^{1/2}}\right]$

Parallel plate capacitor

- model as infinite planes:

$E_{out} = 0$

$E_{in} = \frac{\eta}{\varepsilon_0}$

** limits, as $x \to \infty$, all finite objects look like point charges

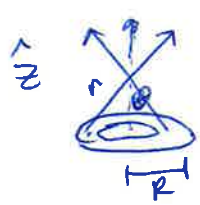
- sometimes, must ~~be~~ use binomial approx to get behavior @ ∞. disk o'ch $\to 0$ if you don't use it.

$(1+x)^n \sim 1 + nx$ for $x \ll 1$

Coulomb

$E = k\int \frac{dQ}{r^2}$ $\qquad dQ = \lambda dl \sim \sigma dA \sim \rho dV$

be careful of symmetry when integrating!



for ring o'charge, must integrate by saying ~~dQ = λdl~~

$E = E\hat{z}$ $\qquad \cos\theta = z/r$ $\qquad \lambda = Q/2\pi R$

$r = \sqrt{z^2+R^2}$ $\qquad dl = R\,d\phi$

$dE_{\hat{z}} = dE\cos\theta = \frac{k\lambda\, dl}{r^2}\cos\theta$

$E = k\lambda\int \frac{dl}{r^2}\cos\theta = \frac{kQ}{2\pi R}(R)\int_0^{2\pi} \frac{d\phi}{r^2}\cdot\frac{z}{r}$

$E = \frac{kQ}{2\pi}(2\pi)\left(\frac{z}{r^3}\right) = \frac{kQz}{(R^2+z^2)^{3/2}}$

① symmetry
② integration direction
③ equivalent $\cos\theta$, etc.

motion through a capacitor or uniform field

Kinematics eqn. $F = ma = eE$

find v_s, $a + t$ to get θ deflection

$\bar{E}$ of a dipole

$\ominus \xrightarrow{d} \oplus$ $\boxed{\bar{p} = qd}$ $E_{dipole} = \begin{cases} \frac{K2\bar{p}}{r^3}, \text{ on axis of } \hat{d} \\ \frac{-K\bar{p}}{r^3}, \text{ plane } \perp \text{ to } \hat{d} \end{cases}$

Gauss: $\Phi_E = \int E\,dA = \frac{Q_{in}}{\varepsilon_0}$

current density: $J = neV_d$, $I = JA$ $= \frac{current}{m^2}$ of the cross section $= \frac{A}{m^2}$

continuity eqn

$\frac{\partial \rho}{\partial t} = \bar{\nabla} \cdot \bar{J}$

drift speed $V_d = \frac{e\tau E}{m}$

conductivity $J = \frac{ne^2\tau}{m} E \longrightarrow J = \sigma E \longrightarrow \sigma = \frac{ne^2\tau}{m}$

Capacitors

C depends upon geometry of electrodes

Non-ohmic materials

do not obey $V = IR$

- batteries, semiconductors, capacitors, inductors

convention

$-|\!\!\vdash$ battery

$+$

RC circuit

$Q = Q_0 e^{-t/\tau}$ $I = I_0 e^{-t/\tau}$ $\tau = RC$

$Q = CV \rightarrow$ $\boxed{\begin{aligned} V &= V_0 e^{-t/\tau} \\ &= V_0(1 - e^{-t/\tau}) \end{aligned}}$ decay / charging-up

work $W = F \cdot d = eE \cdot d = e\Delta V$

Magnetostatics

Magnetic Field

Biot-Savart $B = \frac{\mu_0}{4\pi} \frac{I \times \hat{r}}{r^2} = \frac{\mu_0}{4\pi} I \frac{d\bar{l} \times \hat{r}}{r^2}$

the actual length of the segment, not just the direction.

Tesla, $T = \frac{N}{A \cdot m}$

current

$I = \int J \cdot da_\perp$ ~~Φdl~~

if $J = kr$, $I = \int_0^{2\pi} \int_0^r kr' (r' dr' d\phi) = \frac{2\pi}{3} k r^3$

~~$F = q(v \times B)$~~

Force

$\bar{F} = q \bar{v} \times \bar{B} = I(d\bar{l} \times \bar{B})$

cyclotron motion

$E \parallel B$

$v_\parallel B \rightarrow$ helical

$\frac{mv^2}{r} = qvB$

cycloid

$E \perp B$

Solenoid

$B = \begin{cases} \mu_0 n I \hat{z} & \text{inside} \\ 0 & \text{outside} \end{cases}$ $n = N/L$

ring of current

$B = \frac{\mu_0 I}{2R}$ any displacement along center of ring, should reduce to this eqn. as $x \rightarrow 0$, as $x \rightarrow \infty$ should be field of dipole.

infinite wire

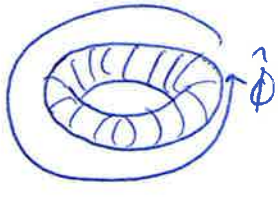
$B = \frac{\mu_0 I}{2\pi R}$ in limits, $\theta_1 = -\pi/2$ $\theta_2 = \pi/2$

Surface current

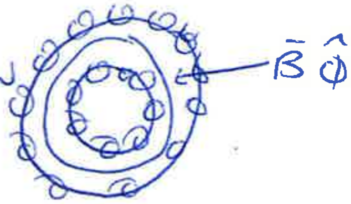
$B = \begin{cases} -\mu_0/2 & z > 0 \\ \mu_0/2 & z < 0 \end{cases}$ use amperian square loop.

toroid

$$B = \begin{cases} \dfrac{\mu_0 I N}{2\pi r}\hat{\phi} & \text{inside} \\ 0 & \text{outside} \end{cases}$$



draw



dipole: $B \propto \frac{\mu}{r^3}$ $\mu = IA$ $x \to \infty$ limit looks like this

field far away from a current loop = field of a dipole

* magnetic fields do no work

Inductance

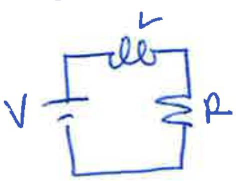
$\Phi = LI$ $\mathcal{E} = -L\frac{dI}{dt}$ $\Phi_B = \int B \cdot dA$

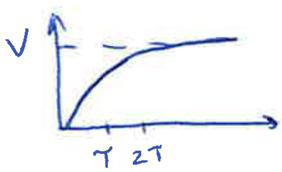
henry: $H = \frac{V}{As}$

$\tau = L/R$

$W = \frac{1}{2}LI^2 = U_{stored}$

* L is like mass, the greater L the harder it is to try & change the current





Ohm's $\mathcal{E}_0 - L\frac{dI}{dt} = IR = V$

soln to DE $\rightarrow$ $I(t) = \frac{\mathcal{E}_0}{R} + ke^{-(R/L)t}$ $\rightarrow \tau = \frac{L}{R}$

If $t=0$, $V=0$, just plugged in, $k = -\frac{\mathcal{E}_0}{R}$

$$I(t) = \frac{\mathcal{E}_0}{R}\left[1 - e^{-(R/L)t}\right]$$

Maxwell's eqns in matter

$\nabla \cdot D = \rho_f$ $\nabla \times \bar{E} = -\partial B/\partial t$ $D = \varepsilon E$ $\varepsilon = \varepsilon_0(1+\chi_e)$

$\nabla \cdot B = 0$ $\nabla \times H = \bar{J}_f + \partial D/\partial t$ $B = \mu H$ $\mu = \mu_0(1+\chi_m)$

dielectrics

dipoles + bound charges

$\rho_b = -\bar{\nabla}\cdot\bar{P}$ $\sigma_b = \bar{P}\cdot\hat{n}$ $\bar{p} = q\bar{d}$ dipole moment

$\tau = \bar{P}\times\bar{E}$ $\bar{U} = -\bar{P}\cdot\bar{E}$

linear dielectrics

electric displacement: $\bar{D} \equiv \varepsilon_0\bar{E} + \bar{P}$

Gauss' law: $\nabla\cdot D = \rho_f$

$\oint D\cdot da = Q_{fenc}$

Linear Dielectrics

condition $\bar{P} = \varepsilon_0\chi_e\bar{E}$ electric susceptibility

$F = \frac{1}{4\pi\varepsilon}\frac{qQ}{r^2} \longrightarrow F = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{qQ}{r^2} = \boxed{\frac{F_{vac}}{\varepsilon_r} = F_{med}}$

only thing that changes

$\varepsilon_0 \to \varepsilon$

$\Downarrow$

$\boxed{E_{m} = \frac{E_{vac}}{\varepsilon_r}} \rightarrow E = \frac{E_0}{K}$

permittivity $= \varepsilon$

dielectric constant: $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$ or $K\varepsilon_0 = \varepsilon$

displacement $\bar{D} = \varepsilon\bar{E}$

*use K for less confusion

Radiation

electric dipole: $P \propto q^2\omega^4 d^2$ $\langle S\rangle \propto \frac{q^2 d^2\omega^4}{r^2}\sin^2\theta$

so don't "see" along direction of motion.

* The $\bar{E}$ is in the plane of motion.

q d q d

2 models, Δq d const

q Δd

point charge $P \propto q^2 a^2$ $\langle S\rangle \propto \frac{q^2 a^2\sin^2\theta}{r^2}$

*no power radiated along motion direction

$\langle S\rangle_{max}$ @ $\theta = 90$ to motion

. Energy equally carried by E/B, $\perp$ S

an oscillating sphere whose radius changes.

emits no radiation. use gauss' law for symmetry problems, E is const.

* an uncharged particle accelerates more than a charged particle b/c the ch. particle emits radiation, $\bar{F}_{in} - \hat{a}$

Magnetic dipole radiation

model: wire loop w/ alternating current

$P \propto b^4 I_0^2 \omega^4$ $\quad\langle S \rangle \propto \frac{b^4 I_0^2 \omega^4 \sin^2\theta}{r^2}$

Maxwell's Eqns

$\nabla \cdot E = \rho/\varepsilon_0 \qquad \nabla \times E = -\partial B/\partial t$

$\nabla \cdot B = 0 \qquad \nabla \times B = \mu_0 J - \mu_0 \varepsilon_0 \frac{\partial E}{\partial t}$

magnetic monopoles: would symmetrize the eqns.

$\oint E \cdot dA = \frac{Q_{in}}{\varepsilon_0} \qquad \oint E \cdot dl = -\frac{\partial \Phi_B}{dt}$

$\oint B \cdot dA = 0 \qquad \oint B \cdot dl = \mu_0 I + \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t}$

Ampere's Law: $\oint B \cdot dl = \mu_0 I_{encl}$

current: $I = \int J \cdot da$

Boundary conditions E/M waves

$E_{\parallel} = 0 \quad B_{\perp} = 0 \rightarrow$ reflections

for reflection, $E_{tot} = 0 \quad B_{tot} = 2B_{wave}$

$E_{\perp}$ is always discontinuous by σ/ε_0 @ boundary

$E_{\parallel}$ is always continuous

$$\begin{cases} \epsilon_1 E_1^{\perp} - \epsilon_2 E_2^{\perp} = \sigma_F & E_1^{\parallel} = E_2^{\parallel} \\ B_1^{\perp} = B_2^{\perp} & \frac{1}{\mu_1} B_1^{\parallel} - \frac{1}{\mu_2} B_2^{\parallel} = K_f \times \hat{n} \end{cases}$$

free current

E/M fields: E/B are in phase & $\perp$

$B_0 = \frac{k}{\omega} E_0 = \frac{1}{c} E_0$

Energy density: $\langle u \rangle = \frac{1}{2} \varepsilon_0 E^2$

Intensity: $I = \langle S \rangle = \frac{1}{2} c \varepsilon_0 E^2$

radiation pressure: $P = \frac{\langle S \rangle}{c}$

$\bar{S} = \frac{1}{\mu_0} (\bar{E} \times \bar{B})$

$\hat{S}$ = propagation of E/M field

Energy stored in E/M : $u = \varepsilon_0 E^2 = \frac{1}{\mu_0} B^2$ $\quad u_E = u_B$

poynting vector : $\bar{S} = \frac{1}{\mu_0} \bar{E} \times \bar{B}$

Irradiance: $I = \langle S \rangle$
$= c\varepsilon_0 \langle E^2 \rangle = \frac{c}{\mu_0} \langle B^2 \rangle$

Relativistic E/M

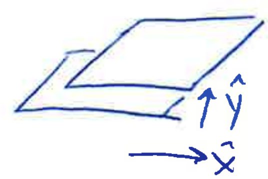
- E/M consistent w/ relativity
- btwn ref. frames the E/M processes change but particle motion, outcome is always the same.
- charge is invariant

example : parallel plate capacitor

p. 526 $\quad S: E = \pm \frac{\sigma_0}{\varepsilon_0} \hat{y} \qquad S': E = \pm \frac{\sigma}{\varepsilon_0} \hat{y}$ $\quad$ only σ changes

- charge on each plate is invariant, width is unchanged, but the length (along direction of motion) is contracted

$\quad l = \gamma l_0 \longrightarrow \sigma = \gamma \sigma_0$



* motion in $\hat{x}$, $E\hat{y}$ is changed
$\qquad E\hat{x}$ is unchanged
since $E = E\hat{y}$ ~~and~~

$$\boxed{\begin{aligned} E_\perp &= \gamma E_\perp \\ E_\parallel &= E_\parallel \end{aligned}}$$

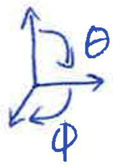
Special cases :

If $B=0$ in any one ref frame
$$\bar{B} = -\frac{1}{c^2}(\bar{v} \times \bar{E})$$
If $E=0$ in any one ref frame
$$\bar{E} = \bar{v} \times \bar{B}$$

Coordinate Systems

Cartesian: $dl = dx\hat{x} + dy\hat{y} + dz\hat{z}$ $\quad dV = dx\,dy\,dz$

Spherical: $dl = dr\hat{r} + r d\theta\hat{\theta} + r\sin\theta d\phi\hat{\phi}$ $\quad dV = r^2\sin\theta\, dr\, d\phi\, d\theta$



$\theta\ 0 \to \pi$
$\phi\ 0 \to 2\pi$

Cylindrical $dl = ds\hat{s} + s d\phi\hat{\phi} + dz\hat{z}$ $\quad dV = s\,ds\,d\phi\,dz$

Vectors

$\nabla \times (\nabla \times A) = \nabla(\nabla \cdot A) - \nabla^2 A$

diamagnetism: caused by Δ in orbital moment (μ) induced by B acts to negate B, antiparallel to B.

paramagnetism: in a B, breaking of energy levels by spin/spin or s/o coupling induced along B.

Ferromag: spontaneous B.

radiation pressure: energy density of the wave

$P = u = U_e + U_B$

$\langle p \rangle = \frac{\langle S \rangle}{c}$

perfect reflection: light enters w/ $+c$ & exits w/ $-c$

So $\Delta v = 2c \to \langle p \rangle = 2\langle S \rangle / c$

Curl-less fields: $\bar{E}$

satisfies 1, satisf. all

1) $\nabla \times F = 0$ everywhere

2) $\int_a^b F \cdot dl =$ path indep.

3) $\oint F \cdot dl = 0$ closed loop

4) $F = -\nabla V$

Div-less fields: $\bar{B}$

1) $\nabla \cdot F = 0$

2) $\int F \cdot dA =$ indep. of any bound line

3) $\oint F \cdot dA = 0$ $\forall$ surf

4) $\bar{F} = \bar{\nabla} \times \bar{A}$