Physics 132-04 Final Exam

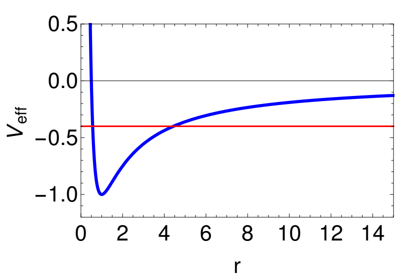
I pledge that I have neither given nor received unauthorized assistance during the completion of this work.

Signature ________________________________

Questions (10 for 4 pts. apiece) Answer in complete, well-written sentences WITHIN the spaces provided.

1. Recall the laboratory where you solved the Schroedinger equation. What requirement or postulate forces us to choose particular energy states? Why?

2. Consider the plot below of the effective potential for a macroscopic particle (blue curve) and its line of constant energy (red curve). What happens at the intersection of the energy 'curve' and the effective potential curve?



3. Recall the laboratory where you started with a mixture of ice and water in a beaker and heated it it to boiling. What is the relationship between the temperature and the added heat while the ice is melting?

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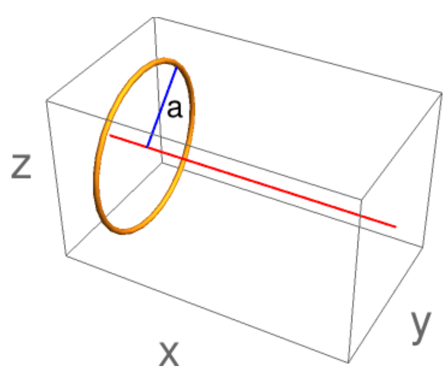
4. Consider an ideal gas in a rigid container that has a fixed volume. How is the molar specific heat defined in terms of the heat added Q and the temperature change ΔT? If the gas is heated by an amount Q, then how much work is done against the fixed container? Explain.

5. Consider two Einstein solids A and B that are in thermal contact and in an initial macrostate defined by N_A, q_A, N_B, and q_B where N refers to the number of atoms and q refers to the number of quanta in each solid. The initial, total multiplicity is Ω_1. One quanta is moved from solid B to solid A and the new, total multiplicity is $\Omega_2 < \Omega_1$. Is it more likely for this change to occur or for the system to remain in its initial state? Explain.

6. Recall the calculation of the electric potential due to a charged ring of radius a on the axis x of the ring as shown in the figure. Is the following step legal? Why or why not?

$$k_e \int \frac{dq}{\sqrt{x^2 + a^2}} = \frac{k_e}{\sqrt{x^2 + a^2}} \int dq$$



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7. In the mass spectrometer the electron 'falls' across a potential difference created by the accelerating voltage to gain a velocity v before it enters the magnetic field region. Assuming the electron starts from rest, what is the relationship between the accelerating voltage V and the kinetic energy K when it leaves the accelerating region and enters the magnetic field? Justify your answer in words or with equations.

8. Is light a particle or a wave? What is your evidence?

9. Consider the anomalous magnetic moment of the electron. The measured value is

$$a_e = 0.00115965218073(28)$$

where the number in parentheses is the uncertainty on the last two digits. The theoretical value (calculated using quantum mechanics) is

$$a_t = 0.00115965218113(86)$$

where again the number in parentheses is the uncertainty on the last two digits. Do experiment and theory agree? Be quantitative in your answer.

10. Two rooms A and B of equal volume are connected by an open passageway and are maintained at two, different temperatures T_A and T_B and $T_A > T_B$. Which room has more air molecules? Explain.

Problems (6). Clearly show all reasoning for full credit. Use a separate sheet to show your work.

1. 8 pts. A room of volume V_0 contains air having equivalent molar mass M_m (in $g/mole$). If the temperature of the room is raised from T_1 to T_2, what mass of air m_a will leave the room? Assume the air pressure is always P_0.

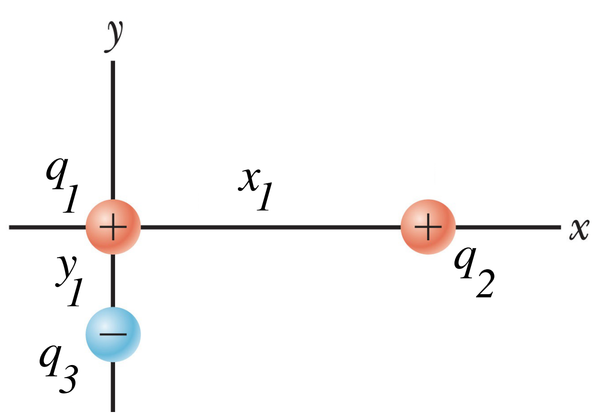
2. 8 pts. A newly-created material has a multiplicity

$$\Omega = \alpha N E$$

where N is the number of atoms in the solid, E is the total, internal energy in the solid, and α is a constant of proportionality.

   1. How does the temperature of the new material depend on the internal energy?
   2. What is the molar heat capacity for this solid?
   3. Could this material really exist? Why or why not?

3. 8 pts. Three point charges are arranged as shown in the figure. What is the vector electric field that q_2 and q_3 create together at the origin? What is the force on q_1? Use the $\hat{\imath}$, $\hat{\jmath}$, $\hat{k}$ notation to express your vectors.



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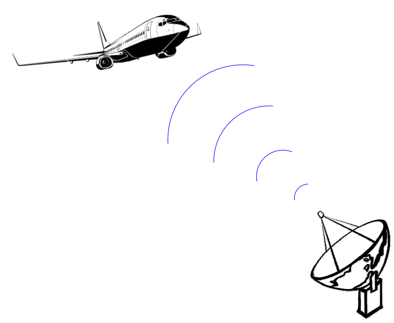
4. 12 pts. A photon with a wavelength λ is absorbed by an electron (mass m_e) confined to a box with infinitely high walls. As a result, the electron moves from the $n = 1$ state to the $n = 4$ state. What is the length of the box in terms of λ and any other constants? What is the chance the electron in the $n = 4$ final state will be found in the left-hand half of the box? The wave function and energies of the electron in the box are

$$\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right) \quad 0 < x < a$$

$$= 0 \quad x \leq 0 \text{ and } x \geq L$$

$$E_n = \frac{n^2\pi^2\hbar^2}{2m_e L^2}$$

5. 12 pts. A radar for tracking aircraft must deliver an average intensity of $I_1 = 6\ J/s - m^2$ on a distant aircraft to detect it. It operates at a frequency $f = 1.2 \times 10^{10}\ s^{-1}$ from circular radar antenna of radius $r_a = 1\ m$ and emits a power $P_0 = 10^5\ J/s$. From a wave perspective, the antenna acts as a circular aperture. What is the range of the radar system?



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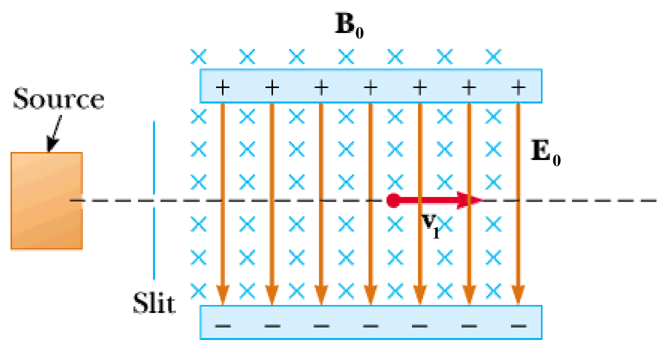
6. 12 pts. In some magnetic spectrometers a device called a velocity selector is used so the beam particles are all moving at the same velocity when they enter the magnetic field. It consists of crossed electric and magnetic fields as shown in the figure where the electric field is $\vec{E} = -E_0\hat{j}$ and the magnetic field goes into the plane of the paper $\vec{B} = -B_0\hat{k}$. Consider a particle of charge q_1 and mass m_1 that goes through the acceleration phase of the mass spectrometer with a voltage drop V_0. What is the kinetic energy K_1 of the particle when it emerges in terms of V_0 and q_1? For a magnetic field of magnitude B_0 what is value of the electric field magnitude E_0 where the charged particle will pass through the velocity selector without a change in direction (*i.e.* straight through)? Will a second particle that goes through the acceleration phase with the same charge q_1, but a different mass m_2 also go through undeviated?



Physics 132-4 Constants

Avogadro's number (N_A)	6.022×10^{23}	Speed of light (c)	$3 \times 10^8\ m/s$
k_B	$1.38 \times 10^{-23}\ J/K$	proton/neutron mass	$1.67 \times 10^{-27}\ kg$
$1\ u$	$1.67 \times 10^{-27}\ kg$	g	$9.8\ m/s^2$
Gravitation constant	$6.67 \times 10^{-11}\ N - m^2/kg^2$	Earth's radius	$6.37 \times 10^6\ m$
Coulomb constant (k_e)	$8.99 \times 10^9 \frac{N-m^2}{C^2}$	Electron mass	$9.11 \times 10^{-31}\ kg$
Elementary charge (e)	$1.60 \times 10^{-19}\ C$	Proton/Neutron mass	$1.67 \times 10^{-27}\ kg$
Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \frac{kg^2}{N-m^2}$	1.0 eV	$1.6 \times 10^{-19}\ J$
1 MeV	$10^6\ eV$	atomic mass unit (u)	$1.66 \times 10^{-27}\ kg$
Planck's constant (h)	$6.626 \times 10^{-34}\ J - s$	Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \frac{kg^2}{N-m^2}$
Planck's constant 2 ($\hbar = h/2\pi$)	$1.0546 \times 10^{-34}\ J - s$	R	$8.31 J/K - mole$

Physics 132-4 Equation Sheet, Final

$$\vec{F} = m\vec{a} = \frac{d\vec{p}}{dt} \quad a_c = \frac{v^2}{r} \quad KE = \frac{1}{2}mv^2 \quad ME_0 = ME_1 = KE_1 + PE_1 \quad \vec{p} = m\vec{v} \quad \vec{p}_0 = \vec{p}_1$$

$$x = \frac{a}{2}t^2 + v_0 t + x_0 \quad v = at + v_0 \qquad Q = C\Delta T = cm\Delta T = nC_v\Delta T \quad Q_{f,v} = mL_{f,v}$$

$$\Delta E_{int} = Q + W \quad W = \int \vec{F}\cdot d\vec{s} \rightarrow P\Delta V \quad \langle\vec{F}\rangle = \frac{\Delta\vec{p}}{\Delta t} \quad P = \frac{|\vec{F}|}{A} \quad PV = Nk_BT = nRT$$

$$\vec{I} = \int \vec{F}dt = \langle\vec{F}\rangle\Delta t = \Delta\vec{p} \quad \langle KE\rangle = \langle E_{kin}\rangle = \frac{1}{2}m\overline{v^2} \quad \langle E_{kin}\rangle = \frac{3}{2}k_BT \quad E_{int} = N\langle E_{kin}\rangle = \frac{3}{2}Nk_BT$$

$$v_{rms} = \sqrt{\langle v^2\rangle} \quad C_V = \frac{f}{2}N_Ak_B \quad E_f = \frac{k_BT}{2} \quad E_{int} = \frac{f}{2}Nk_BT \quad f \equiv \text{number of degrees of freedom}$$

$$E_{atom} = (n_x + n_y + n_z + \frac{3}{2})\epsilon_i \quad E = \sum_{i=1}^{3N} n_i\epsilon_i = q\epsilon_i \quad \Omega(N,q) = \frac{(q+3N-1)!}{q!(3N-1)!}$$

$$S = k_B\ln\Omega \quad \frac{1}{T} = \frac{dS}{dE} \quad q = \frac{E}{\hbar\omega_0} \quad C = \frac{1}{n}\frac{dE}{dT} \quad E = 3Nk_BT$$

$$\vec{F}_C = k_e\frac{q_1q_2}{r^2}\hat{r} \quad \vec{E} \equiv \frac{\vec{F}}{q_0} \quad \vec{E} = k_e\sum_i\frac{q_i}{r_i^2}\hat{r}_i \quad \vec{E} = k_e\int\frac{dq}{r^2}\hat{r}$$

$$\vec{E}_{plate} = 2\pi k_e\sigma\hat{k} \quad \vec{E}_{ring} = k_e\frac{qz}{(z^2+R^2)^{3/2}}\hat{k} \quad \Delta V \equiv \frac{\Delta PE}{q_0} = -\int_A^B \vec{E}\cdot d\vec{s} \quad V = k_e\frac{q}{r} \quad PE = qV$$

$$V = k_e\sum_n\frac{q_n}{r_n} \quad V = k_e\int\frac{dq}{r} \quad V = Ed \quad E_x = -\frac{\partial V}{\partial x} \quad E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial z}$$

$$I \equiv \frac{dQ}{dt} \quad V = IR \quad P = IV \quad R_{equiv} = \sum R_i \quad \frac{1}{R_{equiv}} = \sum\frac{1}{R_i}$$

The algebraic sum of the potential changes across all the elements of a closed loop is zero.

The sum of the currents entering a junction is equal to the sum of the currents leaving the junction.

$$I = nev_dA \quad v_d = \frac{eE\tau}{m_e} \quad \tau = \frac{l_{avg}}{v_{avg}} \quad l_{avg} = \frac{1}{\sqrt[3]{n}} \quad \langle E\rangle = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$$

$$\vec{F}_B = q\vec{v} \times \vec{B} \quad |\vec{F}_B| = |qvB\sin\theta| \quad \vec{F}_c = -m\frac{v^2}{r}\hat{r} \qquad \frac{dN}{dt} = -\lambda t \quad N = N_0 e^{-\lambda t} \quad t_{1/2} = \frac{\ln 2}{\lambda}$$

$$y = A\cos(kx - \omega t) \quad k\lambda = 2\pi = \omega T \quad \frac{\lambda}{T} = c \quad f = \frac{1}{T}$$

$$E = E_m \sin(kx - \omega t) \quad B = B_m \sin(kx - \omega t) \quad \vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \quad |\vec{S}| = I = \frac{E^2}{\mu_0 c} \quad \frac{E_m}{B_m} = c$$

$$I = 4I_0\cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right) \quad I = I_m\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2 \quad I = I_m\cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right)\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2$$

$$\delta = d\sin\theta = m\lambda \quad \delta = a\sin\theta = m\lambda \quad \phi = k\delta \quad \sin\theta_R = \frac{\lambda}{a}$$

$$L = I\omega = mv_t r \quad I \ \sum m_i r_i^2 \quad I = I_{cm} + mR^2 \quad L_0 = L_1 \quad E = \frac{1}{2}mv_r^2 + \frac{L^2}{mr^2} - k_e\frac{e^2}{r}$$

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \quad E_n = -\frac{13.6\ eV}{n^2} \quad E = hf = h\frac{c}{\lambda}$$

$$-\frac{\hbar^2}{2m}\left(\frac{d^2}{dr^2}\right)\Psi(r) + \frac{L^2}{2mr^2}\Psi(r) + V\Psi(r) = E\Psi(r)$$

$$\frac{df(x)}{dx} = \lim_{\Delta x\to 0}\frac{f(x+\Delta x) - f(x)}{\Delta x} \quad \frac{dx^n}{dx} = nx^{n-1} \quad \frac{de^x}{dx} = e^x \quad \frac{df(u)}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}f(x)\cdot g(x) = f\frac{dg}{dx} + g\frac{df}{dx} \quad \frac{d\ln x}{dx} = \frac{1}{x} \quad \frac{d}{dx}\cos ax = -a\sin ax \quad \frac{d}{dx}\sin ax = a\cos ax$$

$$\int_a^b f(x)dx = \lim_{\Delta x\to 0}\sum_{n=1}^{N} f(x)\Delta x \quad \int x^n dx = \frac{x^{n+1}}{n+1} \quad \int \sin^2(ax)dx = \frac{x}{2} - \frac{\sin(ax)}{4a}$$

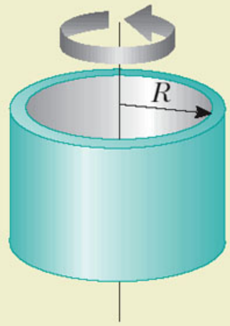
$$\int e^x dx = e^x \quad \int \frac{1}{x}dx = \ln x \int \frac{1}{\sqrt{x^2+a^2}}dx = \ln\left[x + \sqrt{x^2+a^2}\right] \quad \int \frac{x}{\sqrt{x^2+a^2}}dx = \sqrt{x^2+a^2}$$

$$\int \frac{x^2}{\sqrt{x^2+a^2}}dx = \frac{1}{2}x\sqrt{x^2+a^2} - \frac{1}{2}a^2\ln\left[x + \sqrt{x^2+a^2}\right] \quad \int \frac{x^3}{\sqrt{x^2+a^2}}dx = \frac{1}{3}(-2a^2+x^2)\sqrt{x^2+a^2}$$

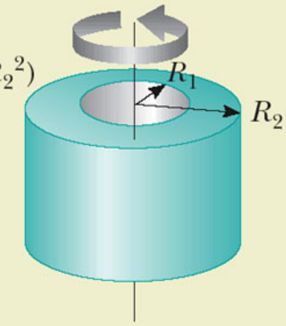
$$\langle x\rangle = \frac{1}{N}\sum_i x_i \quad \sigma = \sqrt{\frac{\sum_i (x_i - \langle x\rangle)^2}{N-1}} \quad N = \frac{b-a}{\Delta x} \quad A = 4\pi r^2 \quad V = Ah \quad V = \frac{4}{3}\pi r^3$$

TABLE 10.2 Moments of Inertia of Homogeneous Rigid Objects With Different Geometries

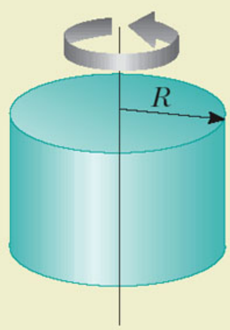
Hoop or thin cylindrical shell
$I_{CM} = MR^2$



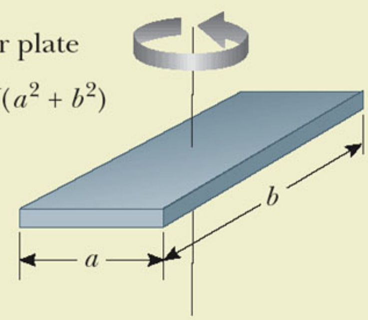
Hollow cylinder
$I_{CM} = \frac{1}{2}M(R_1{}^2 + R_2{}^2)$



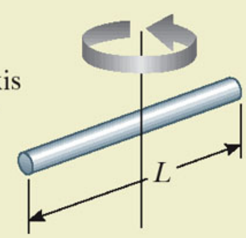
Solid cylinder or disk
$I_{CM} = \frac{1}{2}MR^2$



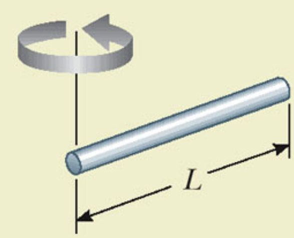
Rectangular plate
$I_{CM} = \frac{1}{12}M(a^2 + b^2)$



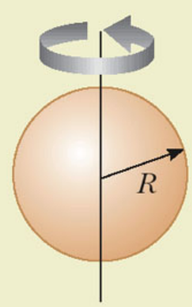
Long thin rod with rotation axis through center
$I_{CM} = \frac{1}{12}ML^2$



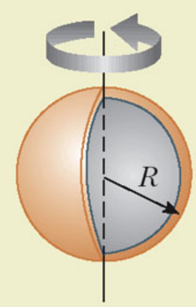
Long thin rod with rotation axis through end
$I = \frac{1}{3}ML^2$



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



Thin spherical shell
$I_{CM} = \frac{2}{3}MR^2$



hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]