Physics 205 Final

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

Name ____________________ Signature ____________________

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

1. Imagine a small magnet with its North pole vertically upward passing near the North pole of an external magnet that is *below* the small magnet. In what direction does the net force acting on the magnet point? Explain.

2. Consider an ensemble of electrons with an initial spin state

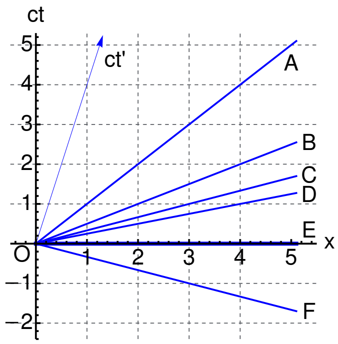
$$|\psi\rangle = \begin{bmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \end{bmatrix}$$

If we send these electrons into an SGx device, what is the probability that a given electron will be determined to have its spin antialigned with the $+x$ direction? Explain.

3. What is locality? What is reality? Answer in the context of Bell's Theorem and the EPR argument.

4. A spaceship departs from the solar system (Event A) and travels at a constant velocity to a distant star. It then returns at a constant velocity to the solar system (event B). A clock on the spaceship measures what kind of time interval - proper, coordinate, spacetime? Explain.

5. Consider the figure below. Suppose the marks on the ct axis are 1.0 cm apart. What should be the *vertical* separation of the corresponding marks on the t' axis? Explain.



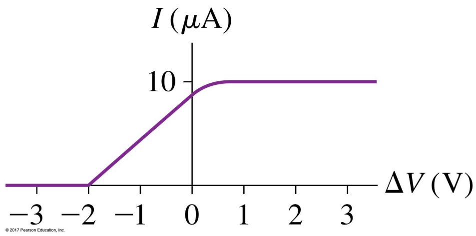
6. Consider the figure above in Question 5. Which of the choices in the figure best correspond to the x' axis? Explain.

7. In a double-slit experiment how could you increase the spacing between the fringes? You can alter the experimental setup in any physically available way like moving the components, swapping out components, changing the light source, *etc.* Explain.

8. Does a long-wavelength photon, because it is larger, carry more energy than a short-wavelengh photon? Explain.

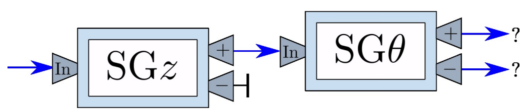
9. To create an interference pattern does the quanton beam's de Broglie wavelength have to be larger than an individual quanton? Explain.

10. The figure shows the measured current vs. ΔV for a photoelectric effect experiment with an unknown metal. How would this result change if the metal was replaced with a different metal with a smaller work function? Explain.

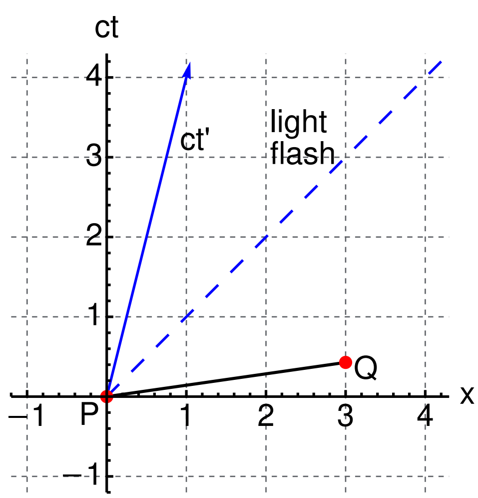


Problems (6). Clearly show all reasoning for full credit. Use a separate sheet for your work.

1. 8 pts. Consider the experiment shown below. If the probabilities that an electron entering the second SG device leaves by the plus and minus channels are $\frac{1}{4}$ and $\frac{3}{4}$, respectively, what are all the possible values of the angle θ of that device's axis? Are the results for the two channels consistent? Show how the probabilities are determined from the wave functions.



2. 8 pts. Consider the spacetime diagram shown below. The events at points P and Q are claimed to be causally connected, *i.e.* the event at Q is caused by the event at P. Is that true? Show your reasoning graphically. There is a bigger version of the figure on page 5. Explain your procedure.



See large version on page 5.

DO NOT WRITE BELOW THIS LINE.

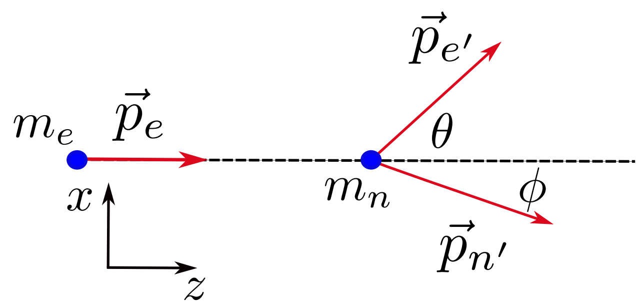
3. 10 pts. An electron of energy E scatters elastically off a nucleon target as shown in the figure. The energy of the scattered electron E' is

$$E' = \frac{E}{1 + \frac{2E}{m_n} \sin^2 \frac{\theta}{2}}$$

where θ is the angle the electron makes with the beam axis. Show the angle ϕ of the proton with respect to the beam direction is the following.

$$\phi = \tan^{-1} \left(\frac{E' \sin\theta}{E - E' \cos\theta} \right)$$

The electron energies E and E' are ultra-relativistic - they are far greater than the electron rest mass.

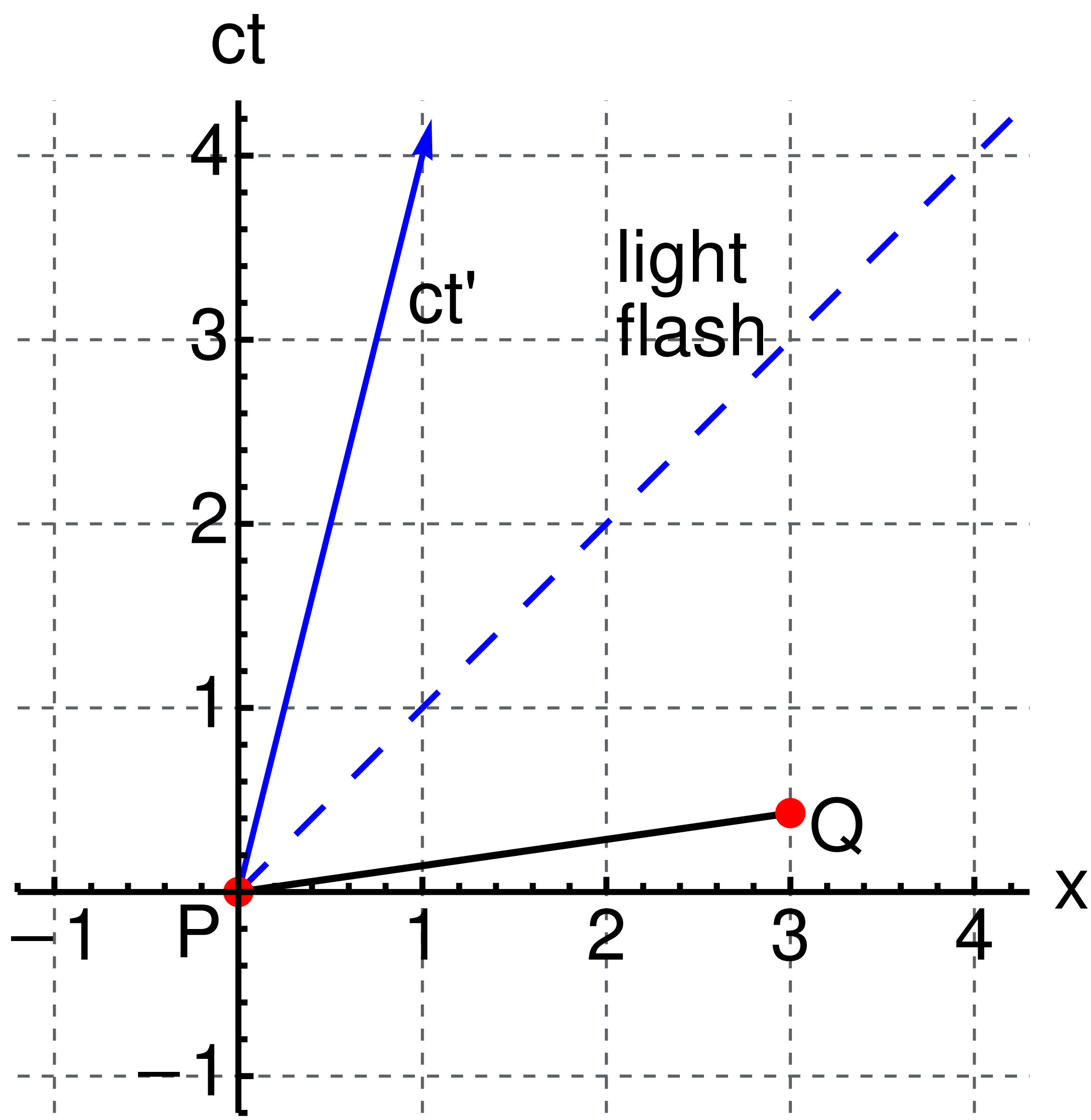


4. 10 pts. The nucleus of an atom is on the order of 10^{-14} m in diameter. For an electron to be confined to a nucleus, its de Broglie wavelength would have to be on this order of magnitude or smaller. (a) What would be the kinetic energy of an electron confined to this region? (b) Make an order-of-magnitude estimate of the electric potential energy of a system of an electron inside an atomic nucleus. (c) Would you expect to find an electron in a nucleus? Explain.

5. 12 pts. Imagine that we create a beam of electrons with an electron gun set at a voltage $\Delta V = 55$ J/C. (a) What is the de Broglie wavelength of the electrons? (b) We are able to measure the $m = 1$ bright spots in the double-slit interference pattern created by this electron beam down to $\theta = 20°$. What slit separation does this correspond to? (c) Do you think seeing the double-slit interference pattern with this electron beam is doable?

6. 12 pts. A photoelectric experiment is performed with an aluminum cathode. An electron inside the cathode has a speed $v_i = 1.5 \times 10^6$ m/s. If the potential difference between the anode and the cathode is $\Delta V = -2.0$ V, what is the highest possible speed v_f the electron can have when it reaches the anode? The work function of aluminum is $W_{Al} = 2.16$ eV.

For Problem 2



Physics 205 Equations

$$\vec{F}_{net} = \sum \vec{F}_i = m\vec{a} = \frac{d\vec{p}}{dt} \quad v = \frac{dx}{dt} \quad v = \frac{\Delta x}{\Delta t} \quad x = \frac{1}{2}at^2 + v_0 t + x_0 \quad v = at + v_0 \quad a_g = -g \quad a_c = \frac{v^2}{r}$$

$$\vec{F}_g = -mg\hat{j} \;\; KE = \frac{1}{2}mv^2 \;\; KE_0 + PE_0 = KE_1 + PE_1 \;\; PE_g = mgh \;\; PE_V = qV \;\; PE_C = \frac{Z_1 Z_2 e^2}{r} = \frac{k_e q_1 q_2}{r}$$

$$\vec{p}_i = \vec{p}_f \quad \vec{p} = m\vec{v} \quad KE_i = KE_f \text{ (elastic)} \quad \vec{F}_C = k_e \frac{q_1 q_2}{r^2}\hat{r} \quad \vec{E} \equiv \frac{\vec{F}}{q_0} \quad d\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{dq}{r^2}\hat{r}$$

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I d\vec{s} \times \hat{r}}{r^2} = \frac{\mu_0}{4\pi}\frac{q d\vec{v} \times \hat{r}}{r^2} \qquad \vec{F}_B = q\vec{v} \times \vec{B} \qquad |\vec{F}_B| = |qvB\sin\theta|$$

$$\vec{E}_B = \vec{E}_A + \vec{v}_{BA} \times \vec{B}_A \quad \vec{B}_B = \vec{B}_A - \mu_0\epsilon_0 \vec{v}_{BA} \times \vec{E}_A \quad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

Galilean Transformation SI units	Lorentz Transformation SI units	Lorentz Transformation SR units
$x' = x - vt$ $y' = y$ $z' = z$ $t' = t$ $v'_x = v_x - v_O$	$x' = \gamma(x - vt)$ $y' = y$ $z' = z$ $t' = \gamma(t - vx/c^2)$ $v'_x = \frac{v_x - v_O}{1 - v_x v/c^2}$	$x' = \gamma(x - \beta t)$ $y' = y$ $z' = z$ $t' = \gamma(t - \beta x)$ $v'_x = \frac{v_x - \beta}{1 - v_x \beta}$

Coordinate Time	Proper Time	Spacetime Interval
Time between two events in an inertial frame measured with synchronized clocks $c\Delta t$,Δt Frame dependent	Time between two events measured by the same clock at both events. $\Delta\tau_{SI}$, $\Delta\tau_{SR}$ Frame independent	Time between two events measured by the same, inertial clock at both events. Δs_{SI}, Δs_{SR} Frame independent

$$\Delta s_{SI}^2 = c^2\Delta t^2 - \Delta d^2 = \Delta s'^2_{SI} \quad \text{or} \quad \Delta s_{SR}^2 = \Delta t^2 - \Delta d^2 = \Delta s'^2_{SR}$$

$$\Delta\tau_{SI} = \int_{t_A}^{t_B} \sqrt{1 - \frac{v^2}{c^2}}\, dt \quad \text{or} \quad \Delta\tau_{SR} = \int_{t_A}^{t_B} \sqrt{1 - \beta^2}\, dt$$

$$\Delta\tau_{SI} = \sqrt{1 - v^2/c^2}\, \Delta t \quad \text{or} \quad \Delta\tau_{SR} = \sqrt{1 - \beta^2}\, \Delta t$$

$$L_{SI} = L_R\sqrt{1-v^2/c^2} \quad \text{or} \quad L_{SR} = L_R\sqrt{1-\beta^2}$$

$$v'_x = \frac{v_x - v}{1 - v_x v/c^2} \quad v'_y = \frac{v_y\sqrt{1-v_x^2/c^2}}{1 - v_x v/c^2} \quad KE = E - mc^2 \quad \text{SI units}$$

$$v'_x = \frac{v_x - \beta}{1 - v_x \beta} \quad v'_y = \frac{v_y\sqrt{1-\beta^2}}{1 - v_x \beta} \quad KE = E - m \quad \text{SR units}$$

$$\underset{\sim}{p}_i = \underset{\sim}{p}_f \quad \underset{\sim}{p}_1 \cdot \underset{\sim}{p}_2 = \underset{\sim}{p}_3 \cdot \underset{\sim}{p}_4$$

$$\underset{\sim}{p} = m\, d\underset{\sim}{s}/d\tau = [m\frac{dt}{d\tau}, m\frac{dx}{d\tau}, m\frac{dy}{d\tau}, m\frac{dz}{d\tau}] = \frac{m}{\sqrt{1-|\vec{v}|^2}}[1, \vec{v}] \quad \underset{\sim}{p} \cdot \underset{\sim}{p} = E_r^2 - |\vec{p}|^2 = m^2 \qquad \text{SR units}$$

$$\underset{\sim}{p} = m\, d\underset{\sim}{s}/d\tau = [mc\frac{dt}{d\tau}, m\frac{dx}{d\tau}, m\frac{dy}{d\tau}, m\frac{dz}{d\tau}] = \frac{m}{\sqrt{1-v^2/c^2}}[c, \vec{v}] \quad \underset{\sim}{p}c \cdot \underset{\sim}{p}c = E_r^2 - |\vec{p}c|^2 = (mc^2)^2 \qquad \text{SI units}$$

$$y = A\sin(kx - \omega t + \phi) \quad k\lambda = \omega T = 2\pi \quad E = E_m \sin(kx - \omega t + \phi) \quad B = B_m \sin(kx - \omega t + \phi) \quad \phi = k\delta$$

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \quad E = cB \quad \langle|\vec{S}|\rangle = I = \frac{E^2}{2\mu_0 c} = \frac{\text{energy}}{\text{area} \cdot \text{time}} \quad c = \frac{\lambda}{T} = \lambda f$$

$$\delta = d\sin\theta = m\lambda \ (m = 0, \pm1, \pm2, ...) \quad \delta = a\sin\theta = m\lambda \ (m = \pm1, \pm2, ...) \quad \phi = k\delta$$

$$I_{int} = I_m \cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right) \quad I_{diff} = I_m \left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2 \quad I_{total} = I_m \cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right)\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2$$

$$E = hf \quad KE_{max} = eV_{stop} = hf - W \quad c = \lambda f \quad p = \frac{h}{\lambda} \quad KE = \frac{p^2}{2m}$$

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{4E}\right)^2 \frac{1}{\sin^4\left(\frac{\theta_s}{2}\right)} = \frac{\text{area}}{\text{steradian}} \quad d\Omega = r^2 \sin\theta d\theta d\phi \quad ME = \frac{1}{2}mv^2 + PE \quad ME_i = ME_f$$

Observable	S_z	S_x	S_θ
$+\frac{1}{2}\hbar$	$\lvert +z\rangle = \begin{bmatrix}1\\0\end{bmatrix}$	$\lvert +x\rangle = \begin{bmatrix}\sqrt{1/2}\\\sqrt{1/2}\end{bmatrix}$	$\lvert +\theta\rangle = \begin{bmatrix}\cos\frac{\theta}{2}\\\sin\frac{\theta}{2}\end{bmatrix}$
$-\frac{1}{2}\hbar$	$\lvert -z\rangle = \begin{bmatrix}0\\1\end{bmatrix}$	$\lvert -x\rangle = \begin{bmatrix}\sqrt{1/2}\\-\sqrt{1/2}\end{bmatrix}$	$\lvert -\theta\rangle = \begin{bmatrix}-\sin\frac{\theta}{2}\\\cos\frac{\theta}{2}\end{bmatrix}$

$$\frac{d}{dx}(f(u)) = \frac{df}{du}\frac{du}{dx} \quad \frac{d}{dx}(u \cdot v) = \frac{du}{dx} \cdot v + \frac{dv}{dx} \cdot u \quad \int x^n dx = \frac{x^{n+1}}{n+1} \quad \int \frac{1}{x} dx = \ln x$$

$$\frac{d}{dx}(x^n) = nx^{n-1} \quad \frac{de^x}{dx} = e^x \quad \frac{d}{dx}(\ln x) = \frac{1}{x} \quad \frac{d}{dx}(\cos ax) = -a \sin ax \quad \frac{d}{dx}(\sin ax) = a \cos ax$$

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

$$\frac{df(x)}{dx} = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \quad \int_a^b f(x)dx = \lim_{\Delta x \to 0} \sum_{n=1}^{N} f(x)\Delta x$$

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

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

$$\int \sqrt{1-ax^2} dx = \frac{x}{2}\sqrt{1-ax^2} + \frac{\arcsin(\sqrt{a}x)}{2\sqrt{a}} \quad \int \frac{x^3}{\sqrt{x^2+a^2}} dx = \frac{1}{3}(-2a^2 + x^2)\sqrt{x^2+a^2}$$

$$x = \frac{-b \pm \sqrt{b^2-4ac}}{2a} \quad \vec{A} \cdot \vec{B} = AB\cos\theta \quad |\vec{A} \times \vec{B}| = |AB \sin\theta|$$

Physics 205 Constants and Conversions

Avogadro's number (N_A)	6.022×10^{23}	Speed of light (c)	$3 \times 10^8\ m/s$
k_B	$1.38 \times 10^{-23}\ J/K$	Elementary charge (e)	$1.60 \times 10^{-19}\ C$
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)	$8.99 \times 10^9 \frac{N-m^2}{C^2}$	Coulomb constant (e^2)	$\hbar c/137$
Proton/Neutron mass	938 MeV/c^{2}g	Proton/Neutron mass	$1.67 \times 10^{-27}\ kg$
Electron mass	$9.11 \times 10^{-31}\ kg$	Electron mass	0.511 MeV/c^2
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)	$6.63 \times 10^{-34}\ Js$	Planck's constant (h)	$4.14 \times 10^{-15}\ eVs$
Planck's constant ($\hbar c$)	197 MeV − fm	Planck's constant ($\hbar c$)	1970 eV − Å
Permeability constant (μ_0)	$1.26 \times 10^{-6}\ Tm/A$	Rydberg constant (R_H)	$1.097 \times 10^7\ m^{-1}$
Becquerel (Bq)	$1\ decay/s$	Curie (Ci)	$3.7 \times 10^{10}\ Bq$

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]

The Periodic Chart.