

Physics 111

Exam #3

November 3, 2025

Name _____

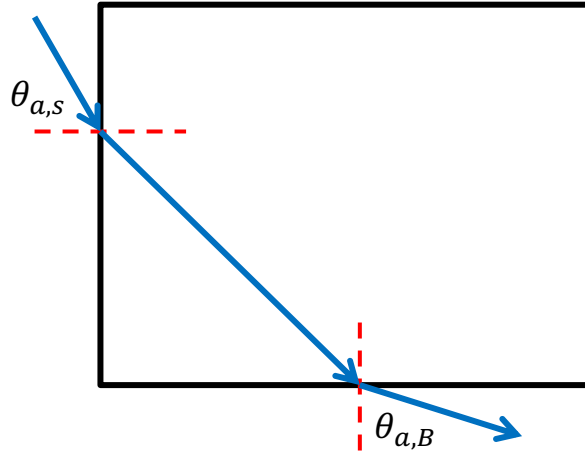
Please read and follow these instructions carefully:

- Read all problems carefully before attempting to solve them.
- Your work must be legible, and the organization clear.
- You must show all work, including correct vector notation.
- You will not receive full credit for correct answers without adequate explanations.
- You will not receive full credit if incorrect work or explanations are mixed in with correct work. So, erase or cross out anything you don't want graded.
- Make explanations complete but brief. Do not write a lot of prose.
- Include diagrams.
- Show what goes into a calculation, not just the final number. For example,
 $|\vec{p}| \approx m|\vec{v}| = (5\text{kg}) \times (2\frac{\text{m}}{\text{s}}) = 10\frac{\text{kg}\cdot\text{m}}{\text{s}}$
- Give standard SI units with your results unless specifically asked for a certain unit.
- Unless specifically asked to derive a result, you may start with the formulas given on the formula sheet including equations corresponding to the fundamental concepts.
- Go for partial credit. If you cannot do some portion of a problem, invent a symbol and/or value for the quantity you can't calculate (explain that you are doing this), and use it to do the rest of the problem.
- Each free-response part is worth 6 points.

Problem #1	/24
Problem #2	/24
Problem #3	/24
Total	/72

I affirm that I have carried out my academic endeavors with full academic honesty.

1. Light from a blue laser pointer, rated at $2mW$, is aimed at a block of transparent material of unknown index of refraction n_m . The block of material is surrounded on all sides by air and the light strikes the left-hand side at $\theta_{a,S} = 45^\circ$ and exits the bottom at $\theta_{a,B} = 76^\circ$, as shown in the diagram below.



- a. What is the index of refraction of the material? You may need the fact that $\sin(90 - \alpha) = \cos \alpha$.

$$n_a \sin \theta_{a,S} = n_m \sin \theta_{m,S}$$

$$n_m \sin(90 - \theta_{m,S}) = n_m \cos \theta_{m,S} = n_a \sin \theta_{a,B}$$

$$\frac{n_a \sin \theta_{a,S}}{n_a \sin \theta_{a,B}} = \frac{n_m \sin \theta_{m,S}}{n_m \cos \theta_{m,S}} \rightarrow \tan \theta_{m,S} = \frac{\sin \theta_{a,S}}{\sin \theta_{a,B}} = \frac{\sin 45}{\sin 76} \rightarrow \theta_{m,S} = 36.1^\circ$$

$$n_a \sin \theta_{a,S} = n_m \sin \theta_{m,S} \rightarrow n_m = \left(\frac{\sin \theta_{a,S}}{\sin \theta_{m,S}} \right) n_{air} = \left(\frac{\sin 45}{\sin 36.1} \right) \times 1.0 = 1.2$$

- b. What is the critical angle of incidence on the lower surface and what is the maximum angle of incidence of the light on the left-hand surface that will lead to total internal reflection of the light in the material?

$$n_m \sin \theta_c = n_a \sin 90 \rightarrow \theta_c = \sin^{-1} \left(\frac{n_a}{n_m} \right) = \sin^{-1} \left(\frac{1.0}{1.2} \right) = 56.1^\circ$$

To see if the actual angle of incidence produces total internal reflection or not, we need to see what angle we actually need on the left-hand side.

$$\theta_{m,s} + \theta_c = 90^\circ \rightarrow \theta_{m,s} = 90^\circ - \theta_c = 90^\circ - 56.1^\circ = 33.6^\circ$$

$$n_a \sin \theta_{a,s} = n_m \sin \theta_{m,s} \rightarrow \sin \theta_{a,s} = \left(\frac{n_m}{n_1} \right) \sin \theta_{m,s} = \left(\frac{1.2}{1.0} \right) \sin 33.6$$

$$\rightarrow \theta_{a,s} = 41.6^\circ$$

This is the maximum angle of incidence and any angle smaller than this will produce internal reflection. As $\theta_{a,s}$ gets smaller, $\theta_{m,s}$ gets smaller and the angle of the light incident on the lower surface would be greater than the critical angle and we'd get TIR. At the angle we have set (which is larger than this maximum angle), we will not get TIR as can be seen by the exiting light at the bottom surface.

- c. Suppose the blue light that exits the transparent material is incident on a calcium surface ($\phi = 2.9\text{eV}$). Electrons are ejected with a maximum kinetic energy 0.12eV . What is the wavelength of the blue light that was used?

$$K = \frac{hc}{\lambda} - \phi \Rightarrow \lambda = \frac{hc}{K + \phi} = \frac{6.63 \times 10^{-34} \text{Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{(0.12\text{eV} + 2.9\text{eV}) \times \frac{1.6 \times 10^{-19} \text{J}}{1\text{eV}}}$$

$$\lambda = 4.12 \times 10^{-7} \text{m} = 412 \text{nm}$$

- d. How many photons are incident on the calcium surface per second and what is the power carried away by those ejected electrons? Assume the efficiency of photoelectron production is 80%.

$$P = \frac{\text{energy}}{\text{time}} = \frac{\text{number of photons}}{\text{time}} \times \frac{\text{energy}}{\text{photon}} \rightarrow \frac{\text{number of photons}}{\text{time}} = \frac{P}{\frac{\text{energy}}{\text{photon}}}$$

$$\frac{\text{number of photons}}{\text{time}} = 2 \times 10^{-3} \frac{\text{J}}{\text{s}} \times \frac{1 \text{ photon}}{(0.12 \text{ eV} + 2.9 \text{ eV}) \times \frac{1.6 \times 10^{-19} \text{ J}}{1 \text{ eV}}}$$

$$\frac{\text{number of photons}}{\text{time}} = 4.1 \times 10^{15} \text{ s}^{-1}$$

For every say, 10 photons in, we get 8 electrons out since the system is 80% efficient.

$$P_e = \frac{\text{number of photons}}{\text{time}} \times \frac{0.8e}{1 \text{ photon}} \times \frac{\text{energy}}{1e}$$

$$P_e = 4.1 \times 10^{15} \text{ s}^{-1} \times 0.8 \times 0.12 \text{ eV} \times \frac{1.6 \times 10^{-19} \text{ J}}{1 \text{ eV}}$$

$$P_e = 6.36 \times 10^{-5} \text{ W} = 0.0636 \text{ mW}$$

2. Students were conducting a laboratory experiment involving a thin converging lens. Objects are placed at various distances from the lens and data are taken on the corresponding real image distances, where the object and image distances were all measured in millimeters. A plot of $\frac{1}{d_o}$ versus $\frac{1}{d_i}$ was generated and the equation of the fit to the data was found to be $y = -0.98x + 0.021$.
- a. Suppose that the converging lens is placed in a holder and an object is placed to the left of the lens and a screen to the right of the lens. The object to screen distance is fixed at $D = 240\text{mm}$. At what position(s) can the lens be placed, with respect to the object, so that a sharp image is formed on the screen?

$$b = \frac{1}{f} \rightarrow f = \frac{1}{b} = \frac{1}{0.021\text{mm}^{-1}} = 47.6\text{mm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_o} + \frac{1}{D - d_o} = \frac{D}{d_o D - d_o^2} \rightarrow d_o^2 - d_o D + fD = 0$$

$$d_{o1} = \frac{D + \sqrt{D^2 - 4fD}}{2} = \frac{240\text{mm} + \sqrt{(240\text{mm})^2 - 4 \times 47.6\text{mm} \times 240\text{mm}}}{2}$$

$$d_{o1} = 174.5\text{mm}$$

$$d_{o2} = \frac{D - \sqrt{D^2 - 4fD}}{2} = \frac{240\text{mm} - \sqrt{(240\text{mm})^2 - 4 \times 47.6\text{mm} \times 240\text{mm}}}{2}$$

$$d_{o2} = 65.5\text{mm}$$

- b. For the position(s) in part a, what will be the image size of a 1cm tall object on the screen?

$$M_1 = \frac{d_{i1}}{d_{o1}} = \frac{D - d_{o1}}{d_{o1}} = \frac{240\text{mm} - 174.5\text{mm}}{174.5\text{mm}} = 0.38 \rightarrow h_{i1} = M_1 h_o = 0.38\text{cm}$$

$$M_2 = \frac{d_{i2}}{d_{o2}} = \frac{D - d_{o2}}{d_{o2}} = \frac{240\text{mm} - 65.5\text{mm}}{65.5\text{mm}} = 2.7 \rightarrow h_{i2} = M_2 h_o = 2.7\text{cm}$$

- c. Suppose that the lens from part a (call it lens A) is used in combination with a second lens (call this lens B) of unknown focal length f_B . A 1cm tall object is placed 75mm to the left of lens B and Lens A is placed 50mm to the right of lens B. In this configuration a real image is seen 67mm to the right of lens A. What type of lens is lens B and what is its focal length?

$$\frac{1}{f_A} = \frac{1}{d_{oA}} + \frac{1}{d_{iA}} \rightarrow d_{oA} = \left(\frac{1}{f_A} - \frac{1}{d_{iA}} \right)^{-1} = \left(\frac{1}{47.6\text{mm}} - \frac{1}{67\text{mm}} \right)^{-1} = 164.4\text{mm}$$

$$d_{oA} = D + d_{iB} \rightarrow d_{iB} = d_{oA} - D = 164.4\text{mm} - 50\text{mm} = 114.4\text{mm}$$

$$\frac{1}{f_B} = \frac{1}{d_{oB}} + \frac{1}{d_{iB}} \rightarrow f_B = \left(\frac{1}{d_{oB}} - \frac{1}{d_{iB}} \right)^{-1} = \left(\frac{1}{75\text{mm}} - \frac{1}{114.4\text{mm}} \right)^{-1} = 217.8\text{mm}$$

Since the focal length is positive, lens B is a converging lens.

- d. Lenses of type B are used as corrective lenses in a pair of glasses. What refractive error of the eye will these lenses correct. Be sure explain what the eye condition is and why these lenses are the appropriate corrective type. What prescription would the eye doctor need to write for these set of glasses?

The prescription is the power of the lens:

$$P = \frac{1}{f} = \frac{1}{0.2178\text{m}} = +4.6\text{D}$$

Converging lenses are used to correct for hyperopia or farsightedness. In a farsighted eye, the eye can focus the image of a distant object onto the retina. When the object comes in closer to the eye, the resulting image moves behind the retina and is thus out of focus. To correct for this, a converging lens is used. The object located near the eye (the near point) is placed inside the focal length of the corrective lenses to produce a virtual image at a distant point (the far point) in space where the eye can focus it onto the retina.

3. X-rays from a mercury light source with wavelength $\lambda = 0.0176nm$ are incident on a block of carbon.

- a. What is the energy (to three decimal places and in keV), momentum (in $\frac{keV}{c}$) and frequency (in Hz or s^{-1}) of the incident mercury x-rays?

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8 \frac{m}{s}}{0.0176 \times 10^{-9} m} = 1.7 \times 10^{19} s^{-1}$$

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} Js \times 3 \times 10^8 \frac{m}{s}}{0.0176 \times 10^{-9} m} \times \frac{1eV}{1.6 \times 10^{-19} J} \times \frac{1keV}{1000eV} = 70.632keV$$

$$E = pc \rightarrow p = \frac{E}{c} = \frac{70.632keV}{c} = 70.632 \frac{keV}{c}$$

- b. If the x-rays are observed to scatter through an angle $\phi = 160^\circ$, what is the energy (in keV and to three decimal places) of the scattered x-rays?

$$\frac{1}{E'} = \frac{1}{E} + \frac{1 - \cos \phi}{mc^2} = \frac{1}{70.632keV} + \frac{1 - \cos 160}{(511 \frac{keV}{c^2})c^2} \rightarrow E' = 55.699keV$$

- c. Expressed as a fraction of the speed of light, what is the speed of the scattered electron?

$$E = E' + K \rightarrow K = E - E' = 70.632\text{keV} - 55.699\text{keV} = 14.933\text{keV}$$

$$K = (\gamma - 1)mc^2 \rightarrow \gamma = \frac{K}{mc^2} + 1 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \rightarrow v = \sqrt{1 - \frac{1}{\gamma^2}} c$$

$$\gamma = \frac{14.933\text{keV}}{(511\frac{\text{keV}}{c^2})c^2} + 1 = 1.02922$$

$$v = \sqrt{1 - \frac{1}{\gamma^2}} c = \sqrt{1 - \frac{1}{(1.02922)^2}} c = 0.237c$$

- d. At what angle θ was the electron scattered through? Measure your angle with respect to the direction of the incident x-rays, taken to be 0° .

From conservation of momentum in the direction perpendicular to the incident x-rays we have:

$$0 = p_{\text{photon}} \sin \phi - p_e \sin \theta \rightarrow \sin \theta = \left(\frac{p_{\text{photon}}}{p_e} \right) \sin \phi = \left(\frac{p_{\text{photon}} \times c}{p_e \times c} \right) \sin \phi$$

$$\sin \theta = \left(\frac{E_{\text{photon}}}{\gamma m v c} \right) \sin \phi = \left(\frac{55.699\text{keV}}{1.02922 \times 511\frac{\text{keV}}{c^2} \times 0.237c \times c} \right) \sin 160$$

$$\theta = \sin^{-1}(0.1528) = 8.8^\circ$$

Physics 111 Formula Sheet

Electrostatics

$$F = k \frac{q_1 q_2}{r^2}$$

$$\vec{F} = q\vec{E}; \quad E_{pc} = k \frac{q}{r^2}; \quad E_{plate} = \frac{q}{\epsilon_0 A}$$

$$E = -\frac{\Delta V}{\Delta x}$$

$$V_{pc} = k \frac{q}{r}$$

$$U_e = k \frac{q_1 q_2}{r} = qV$$

$$W = -q\Delta V = -\Delta U_e = \Delta K$$

Electric Circuits - Capacitors

$$Q = CV; \quad C = \frac{\kappa \epsilon_0 A}{d}$$

$$C_{parallel} = \sum_{i=1}^N C_i$$

$$\frac{1}{C_{series}} = \sum_{i=1}^N \frac{1}{C_i}$$

$$Q_{charging}(t) = Q_{max} \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$Q_{discharging}(t) = Q_{max} e^{-\frac{t}{\tau}}$$

$$I(t) = I_{max} e^{-\frac{t}{\tau}} = \frac{Q_{max}}{\tau} e^{-\frac{t}{\tau}}$$

$$\tau = RC$$

$$U_C = \frac{1}{2}qV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$$

Light as a Wave

$$c = f\lambda$$

$$S(t) = \frac{\text{Energy}}{\text{time} \times \text{Area}} = c\epsilon_0 E^2(t) = c \frac{B^2(t)}{\mu_0}$$

$$I = S_{avg} = \frac{1}{2}c\epsilon_0 E_{max}^2 = c \frac{B_{max}^2}{2\mu_0}$$

$$P = \begin{cases} \frac{S}{c}; & \text{absorbed} \\ \frac{2S}{c}; & \text{reflected} \end{cases}$$

$$S = S_0 \cos^2 \theta$$

$$v = \frac{c}{n}$$

$$\theta_{incident} = \theta_{reflected}$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$P = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$M = \frac{d_i}{d_o}; \quad |M| = \frac{h_i}{h_o}$$

Magnetism

$$\vec{F} = q\vec{v} \times \vec{B} \rightarrow F = qvB \sin \theta$$

$$\vec{F} = I\vec{L} \times \vec{B} \rightarrow F = ILB \sin \theta$$

$$V_{Hall} = wv_d B$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$\mathcal{E} = \Delta V = -N \frac{\Delta \phi_B}{\Delta t}$$

$$\phi_B = BA \cos \theta$$

Electric Circuits - Resistors

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = neAv_d; \quad n = \frac{\rho N_A}{m}$$

$$V = IR$$

$$R = \frac{\rho L}{A}$$

$$R_{series} = \sum_{i=1}^N R_i$$

$$\frac{1}{R_{parallel}} = \sum_{i=1}^N \frac{1}{R_i}$$

$$P = \frac{\Delta E}{\Delta t} = IV = I^2 R = \frac{V^2}{R}$$

Light as a Particle/Relativity

$$E = hf = \frac{hc}{\lambda}$$

$$K_{max} = hf - \phi$$

$$\Delta \lambda = \lambda' - \lambda = \frac{h}{mc} (1 - \cos \phi)$$

$$\frac{1}{E'} = \frac{1}{E} + \frac{(1 - \cos \phi)}{E_{rest}}; \quad E_{rest} = mc^2$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$p = \gamma mv$$

$$E_{total} = E_{rest} + K = \gamma mc^2$$

$$K = (\gamma - 1)mc^2$$

$$E_{total}^2 = p^2 c^2 + m^2 c^4$$

Nuclear Physics

$$N = N_0 e^{-\lambda t}$$

$$m = m_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

$$A = \lambda N$$

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

Constants

$$g = 9.8 \frac{m}{s^2}$$

$$1e = 1.6 \times 10^{-19} C$$

$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{Nm^2}{C^2}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$$

$$1eV = 1.6 \times 10^{-19} J$$

$$\mu_0 = 4\pi \times 10^{-7} \frac{Tm}{A}$$

$$c = 3 \times 10^8 \frac{m}{s}$$

$$h = 6.63 \times 10^{-34} Js = 4.14 \times 10^{-15} eVs$$

$$N_A = 6.02 \times 10^{23}$$

$$1u = 1.66 \times 10^{-27} kg = 931.5 \frac{MeV}{c^2}$$

$$m_p = 1.67 \times 10^{-27} kg = 937.1 \frac{MeV}{c^2}$$

$$m_n = 1.69 \times 10^{-27} kg = 948.3 \frac{MeV}{c^2}$$

$$m_e = 9.11 \times 10^{-31} kg = 0.511 \frac{MeV}{c^2}$$

Physics 110 Formulas

$$\vec{F} = m\vec{a}; \quad F_G = \frac{GM_1 m_2}{r^2}; \quad F_s = -ky; \quad a_c = \frac{v^2}{r}$$

$$W = -\Delta U_g - \Delta U_s = \Delta K$$

$$U_g = mgy$$

$$U_s = \frac{1}{2}ky^2$$

$$K = \frac{1}{2}mv^2$$

$$\vec{r}_f = \vec{r}_i + \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$

$$\vec{v}_f = \vec{v}_i + \vec{a}t$$

$$v_f^2 = v_i^2 + 2a_r \Delta r$$

Common Metric Units

$$\text{nano (n)} = 10^{-9}$$

$$\text{micro (\mu)} = 10^{-6}$$

$$\text{milli (m)} = 10^{-3}$$

$$\text{centi (c)} = 10^{-2}$$

$$\text{kilo (k)} = 10^3$$

$$\text{mega (M)} = 10^6$$

Geometry/Algebra

$$\text{Circles:} \quad A = \pi r^2 \quad C = 2\pi r = \pi$$

$$\text{Spheres:} \quad A = 4\pi r^2 \quad V = \frac{4}{3}\pi r^3$$

$$\text{Triangles:} \quad A = \frac{1}{2}bh$$

$$\text{Quadratics:} \quad ax^2 + bx + c = 0 \rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

PERIODIC TABLE OF ELEMENTS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18																					
1 H Hydrogen 1.008	Atomic # Symbol Name Weight																2 He Helium 4.0026				
3 Li Lithium 6.94	4 Be Beryllium 9.0122																				
5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																
11 Na Sodium 22.990	12 Mg Magnesium 24.305															13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798				
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29				
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)				
87 Fr Francium (223)	88 Ra Radium (226)	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (268)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)	113 Nh Nihonium (284)	114 Fl Flerovium (289)	115 Mc Moscovium (288)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)				
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																					
57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97							
89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)							
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