

# Physics 111

## Exam #1

January 23, 2026

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

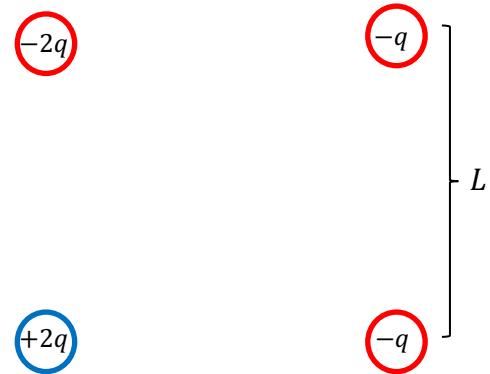
*I affirm that I have carried out my academic endeavors with full academic honesty.*

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1. Consider the following arrangement of four point-charges arranged on the corners of a square. Assume that the square has sides of length  $L$ .

a. How much work was done to assemble this collection of point-charges. Assume each point-charge is brought in one at a time from very far away and put in their final locations.

Starting with the  $+2q$  point-charge and proceeding counterclockwise we have:



$$W_{2q} = 0$$

$$W_{-q} = -(-q) \left[ \frac{k2q}{L} - 0 \right] = \frac{2kq^2}{L}$$

$$W_{-q} = -(-q) \left[ \frac{k(-q)}{L} - 0 \right] - (-q) \left[ \frac{k2q}{\sqrt{2}L} - 0 \right] = -\frac{kq^2}{L} + \frac{\sqrt{2}kq^2}{2L}$$

$$W_{-q} = \left( \frac{\sqrt{2}}{2} - 1 \right) \frac{kq^2}{L}$$

$$W_{-2q} = -(-2q) \left[ \frac{k(-q)}{L} - 0 \right] - (-2q) \left[ \frac{k(-q)}{\sqrt{2}L} - 0 \right] - (-2q) \left[ \frac{k(2q)}{L} - 0 \right]$$

$$W_{-2q} = -\frac{2kq^2}{L} - \frac{2}{\sqrt{2}} \frac{kq^2}{L} + \frac{4kq^2}{L} = \left( 2 - \frac{\sqrt{2}}{2} \right) \frac{kq^2}{L}$$

$$W_{net} = W_{2q} + W_{-q} + W_{-q} + W_{-2q}$$

$$W_{net} = 0 + \frac{2kq^2}{L} + \left( \frac{\sqrt{2}}{2} - 1 \right) \frac{kq^2}{L} + \left( 2 - \frac{\sqrt{2}}{2} \right) \frac{kq^2}{L}$$

$$W_{net} = \left( 2 + \frac{\sqrt{2}}{2} - 1 + 2 - \frac{\sqrt{2}}{2} \right) \frac{kq^2}{L} = 3 \frac{kq^2}{L}$$

b. What is the electric potential energy in this collection of point-charges? Does the sign of the potential energy make sense? Explain in a sentence or two.

$$W = -\Delta U_e = -(U_{ef} - U_{ei}) = -U_{ef} \rightarrow U_{ef} = -W = -3 \frac{kq^2}{L}$$

c. What is the net electric field at the center of the square due to the four point-charges on the corners?

$$E_{net,x} = E_{-q,x} + E_{+2qx} - E_{-2qx} + E_{-qx} = 2E_{-qx} = 2 \left( \frac{kq}{L^2/2} \right) \cos 45 = 2\sqrt{2} \frac{kq}{L^2}$$

$$E_{net,y} = E_{-q,y} + E_{+2qy} + E_{-2qy} - E_{-qy} = 2E_{-2qy} = 2 \left( \frac{kq}{L^2/2} \right) \sin 45 = 4\sqrt{2} \frac{kq}{L^2}$$

$$E_{net} = \sqrt{E_{net,x}^2 + E_{net,y}^2} = \frac{kq}{L^2} \sqrt{(2\sqrt{2})^2 + (4\sqrt{2})^2} = \sqrt{40} \frac{kq}{L^2} = 6.3 \frac{kq}{L^2}$$

$$\tan \phi = \frac{E_{net,y}}{E_{net,x}} = \frac{4\sqrt{2} \frac{kq}{L^2}}{2\sqrt{2} \frac{kq}{L^2}} = 2 \rightarrow \phi = 63^\circ \text{ above the positive x-axis.}$$

d. Suppose that a charge  $Q = -4q$  were placed at the center of the square. What net force would  $Q$  feel?

$$F_{net} = qE_{net} = 4q \cdot \frac{6.3kq}{L^2} = 25.2 \frac{kq^2}{L^2} \text{ in magnitude @ } \theta = 63^\circ + 180^\circ = 243^\circ \text{ measured with respect to the positive x-axis (or } 63^\circ \text{ below the negative x-axis.)}$$

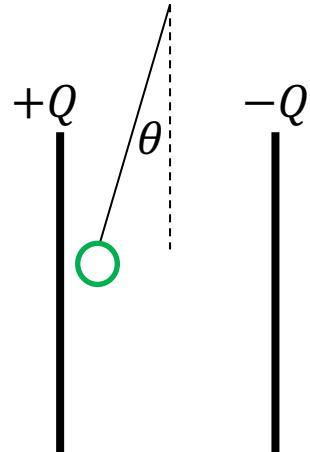
2. A capacitor is constructed out of two circular parallel plates of diameter  $10\text{cm}$  separated by an unknown distance  $d$ . The initially uncharged capacitor is connected to a resistor and a  $1000\text{V}$  battery and charged to its maximum value  $Q_{max}$  where  $Q_{max} = 0.7\text{nC}$ .

a. If the capacitor is air filled, what is the separation between the plates of this capacitor?

$$Q = CV = \left(\frac{\kappa\epsilon_0 A}{d}\right)V \rightarrow d = \frac{\kappa\epsilon_0 AV}{Q}$$

$$d = \frac{1 \cdot 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \cdot \pi(0.05\text{m})^2 \cdot 1000\text{V}}{0.7 \times 10^{-9}\text{C}} = 0.099\text{m} = 0.1\text{m} = 10\text{cm}$$

b. Suppose the capacitor is oriented as shown on the right. At the midpoint between the plates a point-charge  $q$  (the green circle) is suspended from an insulating string of length  $L = 75\text{cm}$ . The point-charge comes into equilibrium when the string makes an angle  $\theta = 20^\circ$  measured with respect to the vertical. What is the magnitude of the electric field between the plates?



$$E = \frac{Q}{\epsilon_0 A} = \frac{0.7 \times 10^{-9}\text{C}}{8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \cdot \pi(0.05\text{m})^2} = 1 \times 10^4 \frac{\text{N}}{\text{C}}$$

Or,

$$E = -\frac{\Delta V}{\Delta x} = -\left(\frac{0\text{V} - 1000\text{V}}{0.099\text{m} - 0\text{m}}\right) = 1 \times 10^4 \frac{\text{V}}{\text{m}}$$

The direction: From the positive to the negative plate.

c. What is the sign of the point-charge  $q$ ? Explain your choice fully to earn full credit. Simply stating positive or negative will earn minimal credit.

Since the electric field points from the positive to the negative plate and the sphere moves to the left in the direction opposite the electric field, the charge on the sphere must be negative.

d. What is the magnitude of the point-charge  $q$  if  $m = 250g$ ?

$$F_{net,x} = -F_e + F_{Tx} = -F_e + F_T \sin \theta = ma_x = 0$$

$$F_{net,y} = F_{Ty} - F_W = F_T \cos \theta - mg = ma_y = 0 \rightarrow F_T = \frac{mg}{\cos \theta}$$

$$\rightarrow qE = F_T \sin \theta = \left(\frac{mg}{\cos \theta}\right) \sin \theta = mg \tan \theta \rightarrow q = \frac{mg}{E} \tan \theta = \frac{0.25kg \cdot 9.8 \frac{m}{s^2}}{1 \times 10^4 \frac{N}{C}}$$

$$q = 8.9 \times 10^{-5} C = 89 \mu C$$

3. Bismuth ( $^{209}_{83}Bi$ ) has a nuclear radius  $r_N$  given by  $r_N = 1.2 \times 10^{-15} m \cdot A^{\frac{1}{3}}$ , where  $A$  is the atomic mass in unified (or atomic) mass units. A proton was accelerated from rest when it is initially very far away from a bismuth and acquired a speed  $v_i$ . The proton approaches the bismuth nucleus head-on and from this interaction the proton is brought momentarily to rest at a distance of  $3r_N$ .

a. What was the initial speed  $v_i$  of the proton when it was very far away from the bismuth nucleus?

$$W = -\Delta U_e = -q\Delta V = \Delta K \rightarrow -q\Delta V = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = -\frac{1}{2}mv_i^2$$

$$-e \left[ \frac{kq_{bi}}{r_r} - \frac{kq_{Bi}}{r_i} \right] = -e \left( \frac{k(83e)}{3r_n} \right) = -\frac{1}{2}mv_i^2$$

$$v_i = \sqrt{\frac{166ke^2}{2mr_N}} = \sqrt{\frac{166 \cdot 9 \times 10^9 \frac{Nm^2}{C^2} \cdot (1.6 \times 10^{-19} C)^2}{3 \times 1.67 \times 10^{-27} kg \cdot 1.2 \times 10^{-15} m \cdot (209)^{\frac{1}{3}}}}$$

$$v_i = 3.3 \times 10^7 \frac{m}{s}$$

b. Through what potential difference was the proton accelerated to give it the speed in part a? Assume the proton started from rest.

$$W = -\Delta U_e = -q\Delta V = \Delta K \rightarrow -q\Delta V = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2$$

$$\Delta V = -\left(\frac{m}{2q}\right)v_f^2 = -\left(\frac{1.67 \times 10^{-27} kg}{2 \cdot 1.6 \times 10^{-19} C}\right)\left(3.3 \times 10^7 \frac{m}{s}\right)^2 = -5.6 \times 10^6 V$$

$$\Delta V = -5.6 MV$$

c. Particle accelerators, like those used to accelerate the proton in part b, are modeled as a capacitor. Suppose the maximum charge that was stored on the capacitor used in this particle accelerator when fully charged was  $Q_{max} = 42.7\mu C$ . If the initially uncharged capacitor was charged through a  $R = 120G\Omega$  resistor, what is the time constant for the charging circuit?

$$Q = CV \rightarrow C = \frac{Q}{V} = \frac{42.7 \times 10^{-6}C}{5.6 \times 10^6V} = 7.6 \times 10^{-12}F$$

$$\tau = RC = 120 \times 10^9 \Omega \cdot 7.6 \times 10^{-12}F = 0.92s$$

d. Assuming that the capacitor in part c was initially uncharged, how long does it take to store 84% of the total potential energy in the system?

$$U_f = \frac{1}{2}CV^2 = \frac{1}{2}CV_{max}^2 \left(1 - e^{-\frac{t}{\tau}}\right)^2 = U_i \left(1 - e^{-\frac{t}{\tau}}\right)^2$$

$$0.84U_i = U_i \left(1 - e^{-\frac{t}{\tau}}\right)^2$$

$$1 - e^{-\frac{t}{\tau}} = \sqrt{0.84} = 0.92$$

$$e^{-\frac{t}{\tau}} = 0.08 \rightarrow t = -0.92\tau \ln 0.08 = -0.92 \cdot 0.92 \ln 0.08 = 2.1s$$

## 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

$$c = f\lambda$$

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

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

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

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

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

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

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

$$P = \frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$$

$$M = \frac{d_i}{d_0}; \quad |M| = \frac{h_i}{h_0}$$

### Magnetism

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

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

$$V_{Hall} = w v_d B$$

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

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

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

### 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

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

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

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

$$A = \lambda N$$

$$t_1 = \frac{\ln 2}{\lambda}$$

## 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

$$\vec{F} = m\vec{a}; \quad F_G = \frac{GM_1m_2}{r^2}; \quad F_s = -ky; \quad a_c = \frac{v^2}{r}$$

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

$$U_g = mgy$$

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

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

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

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

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

## Common Metric Units

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

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

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

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

$$kilo (k) = 10^3$$

$$mega (M) = 10^6$$

## Geometry/Algebra

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

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

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

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

# 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	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 14.0107	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 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948																		
C Solid	Hg Liquid	H Gas	RF Unknown	Metals				Nonmetals				Metalloids				Halogens																			
3 Li Lithium 6.94	4 Be Beryllium 9.0122	5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.0107	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 28.085	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		
4 K Potassium 39.098	5 Ca Calcium 40.078	6 Sc Scandium 44.956	7 Ti Titanium 47.867	8 V Vanadium 50.942	9 Cr Chromium 51.996	10 Mn Manganese 54.938	11 Fe Iron 55.845	12 Co Cobalt 58.933	13 Ni Nickel 58.693	14 Cu Copper 63.546	15 Zn Zinc 65.38	16 Ga Gallium 69.723	17 Ge Germanium 72.630	18 As Arsenic 74.922	19 Se Selenium 78.971	20 Br Bromine 79.904	21 Kr Krypton 83.798	22 Rb Rubidium 85.468	23 Sr Strontium 87.62	24 Y Yttrium 91.224	25 Zr Zirconium 92.206	26 Nb Niobium 91.956	27 Mo Molybdenum 95.99	28 Tc Technetium 97.007	29 Ru Ruthenium 101.07	30 Rh Rhodium 104.42	31 Pd Palladium 106.42	32 Ag Silver 107.87	33 Cd Cadmium 112.41	34 In Indium 114.82	35 Sn Tin 117.81	36 Pb Lead 121.73	37 Te Tellurium 127.60	38 I Iodine 126.90	39 Xe Xenon 131.29
5 Rb Rubidium 85.468	6 Sr Strontium 87.62	7 Y Yttrium 88.906	8 Zr Zirconium 91.224	9 Nb Niobium 92.206	10 Mo Molybdenum 95.99	11 Tc Technetium 97.007	12 Ru Ruthenium 101.07	13 Rh Rhodium 104.42	14 Pd Palladium 106.42	15 Ag Silver 107.87	16 Cd Cadmium 112.41	17 In Indium 114.82	18 Sn Tin 117.81	19 Pb Lead 121.73	20 Te Tellurium 127.60	21 I Iodine 126.90	22 Xe Xenon 131.29	23 Cs Cesium 132.91	24 Ba Barium 137.33	25 La Lanthanum 138.91	26 Ce Cerium 140.912	27 Pr Praseodymium 141.91	28 Nd Neodymium 144.24	29 Pm Promethium 145.00	30 Sm Samarium 150.36	31 Eu Europium 151.96	32 Gd Gadolinium 157.25	33 Tb Thulium 168.93	34 Dy Dysprosium 162.50	35 Ho Holmium 164.93	36 Er Erbium 167.26	37 Tm Thulium 168.93	38 Yb Ytterbium 173.05	39 Lu Lutetium 174.97	
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 183.34	75 Os Osmium 186.21	76 Se Selenium 189.23	77 Hg Mercury 195.09	78 Au Gold 196.97	79 Hg Mercury 200.59	80 Tl Thallium 204.38	81 Pb Lead 207.23	82 Bi Bismuth 208.98	83 Po Polonium 209.20	84 At Astatine 210.20	85 Rn Radon 222.00	86 At Astatine 222.00	87 Fr Francium (223)	88 Ra Radium (226)	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 (247)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (252)	99 Es Einsteinium (252)	100 Fm Fermium (258)	101 Md Mendelevium (258)	102 No Nobelium (256)	103 Lr Lawrencium (266)	
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																																			