Gen. Phys. II **Exam 5 - Chs. 30,31,32 - Atomic & Nuclear Physics** **May. 8, 2018**

Rec. Time **Name**

For full credit, make your work clear. Show formulas used, essential steps, and results with correct units and significant figures. Points shown in parenthesis. For TF and MC, choose the *best* answer.

OpenStax Ch. 30 - Atomic Physics.

1. (3) The first truly *direct* evidence of atoms, discovered in 1827 and explained in one of Einstein's 1905 papers, was

   a. Brownian motion. b. Dalton's Law. c. cathode rays. d. kinetic theory.

2. (3) The scientist who is credited with first measuring the charge to mass ratio of electrons (or cathode rays) was

   a. Dmitri Mendeleev. b. Ernest Rutherford. c. J.J. Thomson. d. Amedeo Avogadro.

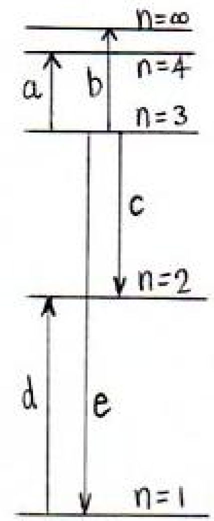
3. (3) Father of nuclear physics Ernest Rutherford discovered the nucleus of gold atoms by bombarding them with

   a. electrons. b. protons. c. neutral hydrogen atoms. d. doubly-charged helium nuclei.

Decide whether these statements about the Bohr atomic model are true or false.

4. (2) **T F** Bohr's model applies only to hydrogen atoms or one-electron ions..
5. (2) **T F** Bohr's model explains the similarities between emission and absorption spectra.
6. (2) **T F** Bohr's model predicts a continuous spectrum of emitted light from atoms.
7. (2) **T F** The de Broglie wavelength in the n^{th} state equals the diameter of the electron's orbit divided by n.

8. (12) The arrows on the diagram show some transitions that a hydrogen atom can make between energy levels, according to the Bohr model. Of the transitions shown,



a) (2) Which transitions correspond to **emission** of radiation by the atom? ____________

b) (2) Which transitions correspond to **absorption** of radiation by the atom? ____________

c) (2) Which transition is ionization of the atom? ______

d) (6) For only the transitions shown, calculate the shortest wavelength *emitted.*

The following questions relate to quantum mechanics (beyond the Bohr model) for atoms.

9. (3) How many electrons in an atom can have the pair of quantum numbers, $n = 3, \ell = 1$?

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10. (3) How many electrons in an atom can have the set of quantum numbers, $n = 3, \ell = 1, m_\ell = 0$?

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11. (6) The highest atomic subshells for cobalt (Co) in its ground state have the configuration $3d^7 4s^2$.

a) (2) What is the value of the orbital quantum number l in the 3d subshell?

a. 0   b. 1   c. 2   d. 3   e. 4

b) (2) What is the maximum number of electrons that could occupy the 3d subshell?

c) (2) Which diagram shows how the 3d electron spins line up (m_s values) in the ground state of cobalt?

a. ↑↑↑↑↑↑↑   b. ↑↑↑↑↑↑↓   c. ↑↑↑↑↑↓↓   d. ↑↑↑↑↓↓↓

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12. (3) For any atom, which of these electron configurations is not allowed? Check all that apply.

a. $1s^2 2s^2 2p^3$ b. $1s^2 2s^2 3p^3$ c. $1s^2 2s^2 2d^3$ d. $1s^2 2s^1 2p^1$ e. $1s^2 2s^1 2p^7$

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13. (3) Into how many different energy levels is the 3d subshell split when a magnetic field is applied ("Zeeman effect")?

a. 2   b. 3   c. 4   d. 5   e. 7   f. 10   g. 14

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14. (3) Which of the following outer subshell configurations would correspond to a noble gas? Check all that apply.

a. $2s^2$ b. $2p^2$ c. $2p^5$ d. $4p^6$ e. $3d^{10}$

OpenStax Ch. 31 - Radioactivity & Nuclear Physics. **Name**________________________________

1. (2) Nuclear isotopes are

   a. nuclei with the same number of protons but different numbers of neutrons.
   b. nuclei with the same number of nucleons but different numbers of neutrons.
   c. nuclei with the same number of neutrons but different numbers of protons.

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2. (2) For a nuclear decay to take place *spontaneously* (like alpha, beta or gamma decays),

   a. the mass of the products must be greater than the mass of the parent nucleus.
   b. the mass of the products must be less than the mass of the parent nucleus.
   c. the mass of the products must be equal to the mass of the parent nucleus.

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3. (2) Carbon-14 forms naturally in Earth's atmosphere due to a nuclear transmution of which element X, according to the reaction, n+X $\rightarrow$ ${}^{14}_{6}$C + p ?

   a. oxygen (O) b. nitrogen (N) c. helium (He) d. hydrogen (H)

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4. (3) A ${}^{56}_{26}$Fe (iron) nucleus contains ______ protons and ______ neutrons and ______ nucleons.

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5. (3) When radon-222 decays by α-emission, what is the daughter nucleus? Give its name, mass number A and atomic number Z.

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6. (3) When cobalt-60 decays by γ-emission, what is the daughter nucleus? Give its name, mass number A and atomic number Z.

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7. (3) When potassium-40 decays by β^- emission, what is the daughter nucleus? Give its name, mass number A and atomic number Z.

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8. (8) Iron (${}^{56}_{26}$Fe) is one of the most strongly bound nuclei. Calculate the binding energy per nucleon for ${}^{56}_{26}$Fe, which has an atomic mass of 55.934942 u. [Make use of this: Hydrogen (i.e., proton+electron) ${}^{1}_{1}$H atomic mass is 1.007825 u, and neutron mass is 1.008665 u.]

9. (8) Phosphorous-32 ($^{32}_{15}$P) decays by β^- emission with a half-life of 14.262 days. If you start with a pure 1.00 gram sample of P-32, what mass of P-32 remains after 30.0 days?

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10. (18) The ratio of carbon-14 to carbon-12 atoms in living things is about 1.3×10^{-12}. Carbon-14 has a half-life of 5730 years and the decay constant is $\lambda = \ln(2)/T_{1/2} = 3.83 \times 10^{-12}\ \mathrm{s}^{-1} = 1.21 \times 10^{-4}\ \mathrm{year}^{-1}$. 250-grams of carbon in a sample of ancient wood has an activity of 15.0 decays/s.

a) (6) About how many C-14 atoms were present in this wood sample when the tree died?

b) (6) Based on its activity, about how many C-14 atoms are now present in the wood sample?

c) (6) How old is the wood sample, in years (i.e., the time passed since the tree died)?

OpenStax Ch. 32 - Applications of Nuclear Physics. **Name**______________________________

1. (3) Ionizing radiation emanating from nuclei is dangerous to the human body because

a. It transforms one element into another element. b. It causes molecules to emit light.
c. It breaks chemical bonds, especially in DNA. d. It causes atoms to recoil from the emission.

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2. (3) Which of the following would be considered ionizing radiation? Check all that apply.

a. 4 MeV α particles. b. 4 keV β^- particles c. 4 keV γ rays. d. 4 eV photons.

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3. (3) Which type of radiation has the largest range (or is the most deeply penetrating)?

a. alpha particles b. beta particles. c. gamma rays.

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4. (3) RBE (relative biological effectiveness or quality factor) accounts for the fact that

a. lighter radiation particles cause more damage. b. damage that is localized is harder to repair.
c. damage that is spread out is harder to repair. d. charged radiation particles cause more damage.

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5. (3) For the same energy particles inside the body, which type of radiation produces the most localized damage that is hardest for the body to repair?

a. α-particles. b. β-particles. γ-rays. d. slow neutrons.

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6. (2) **T F** The annual effective dose due to radon gas is a negligible part of all background radiation.
7. (2) **T F** A radiation exposure of 20 sieverts in one sudden event is likely to be fatal.

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8. (2) Uranium that is enriched for use in reactors is high in

a. iron-56. b. uranium-92. c. uranium-235. d. uranium-238.

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9. (2) Fission of heavy elements can become a chain reaction because fission releases

a. α-particles. b. β-particles. c. γ-rays. d. protons. e. neutrons.

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10. (8) For a 70.0-kg person, the background activity due to carbon-14 within the body is about 3.5 kBq. Each β^- from a carbon-14 decay has an energy of 156.5 keV, and RBE = 1. Calculate the annual effective radiation dose (or dose equivalent, in mSv) if all of the β^- are absorbed within the body.

11. (4) Consider the reaction, ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + X$, where X is some unknown.

a) (2) The type of reaction is a. α-decay. b. β-decay. c. γ-decay. d. fusion. e. fission.

b) (2) What is X?

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12. (4) Consider the reaction, $\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{137}_{56}\mathrm{Ba} + {}^{84}_{36}\mathrm{Kr} + X$, where X is some unknown.

a) (2) The type of reaction is a. α-decay. b. β-decay. c. γ-decay. d. fusion. e. fission.

b) (2) What is X?

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13. (12) The deuterium fusion reaction, ${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \mathrm{n}$, releases an energy output of $Q = 3.27$ MeV. Suppose a nuclear reactor is designed to use this reaction, and it consumes 0.250 μg of deuterium per second.

a) (6) How many of the given reactions are taking place per second?

b) (6) What is the power output of the reactor, in watts (or kW or MW, etc., if more convenient)?

Prefixes

a=10^{-18}, f=10^{-15}, p=10^{-12}, n=10^{-9}, $\mu = 10^{-6}$, m=10^{-3}, c=10^{-2}, k=10^{3}, M=10^{6}, G=10^{9}, T=10^{12}, P=10^{15}

Physical Constants

$k = 1/4\pi\epsilon_0 = 8.988$ GNm^2/C^2 (Coulomb's Law)
$e = 1.602 \times 10^{-19}$ C (proton charge)
$c = 3.00 \times 10^8$ m/s (speed of light)
$m_e = 9.1094 \times 10^{-31}$ kg (electron mass)
$m_n = 1.67493 \times 10^{-27}$ kg = (neutron mass)
$h = 6.62607 \times 10^{-34}$ J·s (Planck's constant)

$\epsilon_0 = 1/4\pi k = 8.854$ pF/m (permittivity of space)
$\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of space)
$c = 2.99792458 \times 10^8$ m/s (exact value in vacuum)
$m_p = 1.67262 \times 10^{-27}$ kg (proton mass)
$hc = 1239.84$ eV·nm (photon energy = hc/λ)
$\hbar = 1.05457 \times 10^{-34}$ J·s (Planck's constant/2π)

Units

$N_A = 6.02 \times 10^{23}$/mole (Avogadro's #)
1.0 eV = 1.602×10^{-19} J (electron-volt)
1 F = 1 C/V = 1 farad = 1 C^2/J
1 A = 1 C/s = 1 ampere = 1 coulomb/second
1 T = 1 N/A·m = 1 tesla = 1 newton/ampere·meter
1 Bq = 1 becquerel = 1 decay/s

1 u = 1 g/N_A = 1.6605×10^{-27} kg = 931.5 MeV/c^2 (mass unit)
1 V = 1 J/C = 1 volt = 1 joule/coulomb
1 H = 1 V·s/A = 1 henry = 1 J/A^2
1 Ω = 1 V/A = 1 ohm = 1 J·s/C^2
1 G = 10^{-4} T = 1 gauss = 10^{-4} tesla
1 Ci = 1 curie = 3.70×10^{10} decays/s = 37.0 GBq

Some Masses (for neutral atoms)

electron = ${}^{0}_{-1}$e = 0.00054858 u = 0.51100 MeV/c^2
neutron = ${}^{1}_{0}$n = n = 1.008665 u = 939.57 MeV/c^2
deuterium = ${}^{2}_{1}$H = d = 2.014102 u
helium-3 = ${}^{3}_{2}$He = 3.016029 u

proton = ${}^{1}_{1}$p = p =1.007276 u = 938.27 MeV/c^2
hydrogen = ${}^{1}_{1}$H = 1.007825 u = 938.78 MeV/c^2
tritium = ${}^{3}_{1}$H = t = 3.016049 u
helium-4 = ${}^{4}_{2}$He = α = 4.002603 u

OpenStax Chapter 30 Equations - Atomic Physics

Bohr Model:

$hf = E_n - E_{n'}$ (quantum jump)
$r_n = \frac{n^2}{Z} r_1$ (Bohr radii)
$E_n = -(13.6 \text{ eV})\frac{Z^2}{n^2}$ (Bohr energies)
$n = 1, 2, 3, ...$ (Bohr's quantum number)

$L = mvr = n\frac{h}{2\pi}$ (Bohr's quantization)
$r_1 = \frac{h^2}{4\pi^2 mke^2} = 52.9$ pm (1st Bohr radius)
$E_n = \frac{1}{2}mv^2 - \frac{kZe^2}{r_n}$ (total energy)
$E = hc/\lambda = (1240 \text{ eV} \cdot \text{nm})/\lambda$ (photons)

Quantum numbers for atoms:

principle quantum number $n = 0, 1, 2, 3...$
orbital quantum number $l = 0, 1, 2...(n - 1)$
magnetic quantum number $m_l = -l$ to $+l$
spin quantum number $m_s = -\frac{1}{2}, \ +\frac{1}{2}$

$E_n = -(13.6 \text{ eV})/n^2$ (energy of hydrogen states)
$L = \sqrt{l(l+1)}\ \hbar$ (angular momentum magnitude)
$L_z = m_l\hbar$ (z-component of $\vec{L}$)
$S_z = m_s\hbar$ (z-comp., spin angular momentum)

shell ($2n^2$ states) means a value of (n) is given.
sub-shell [$2(2\ell+1)$ states] means values of (n, l) are given.
orbital (2 states) means particular (n, l, m_l) are given.
state means particular (n, l, m_l, m_s) are given.

$l = 0, 1, 2, 3, 4, 5, 6...$ are indicated with respective letters: s, p, d, f, g, h,...

Pauli exclusion principle: *No two electrons in an atom can occupy the same quantum state.*

Subshells in order of increasing energy: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, 7p

(They fill in order of increasing $n + l$, or increasing n if there is a tie.)

OpenStax Chapter 31 Equations - Radioactivity & Nuclear Physics

Nuclides:

$A = N + Z$, (mass, neutron, proton numbers)

$r = (1.2 \text{ fm})\ A^{1/3}$ (nuclear radius)

$\Delta E =$[(mass of parts) - (mass of nuclide)]c^2 ← (binding energy)

$Q = [M_{\text{parent}} - M_{\text{products}}]c^2$ ← (disintegration energy)

1 u = 1 gram / 6.02×10^{23} (atomic mass unit)

1 u $\cdot\ c^2$ = 931.5 MeV (energy unit)

Half-life $T_{1/2}$ and decay constant λ

$N = N_0 e^{-\lambda t}$ (decay of parent nuclei)

$N = N_0 \left(\frac{1}{2}\right)^{t/T_{1/2}}$ (decay by half-lives)

$t = \frac{-1}{\lambda} \ln(N/N_0)$ (time when N nuclei remain)

$\mathcal{A} = \left|\frac{\Delta N}{\Delta t}\right| = N\lambda$ (radio-activity)

$\lambda T_{\frac{1}{2}} = \ln 2$ (decay constant, half-life)

$M = Nm$ = mass = (# of nuclei)×(nuclear mass)

$\#({}^{14}_{6}C)/\#({}^{12}_{6}C) = 1.3 \times 10^{-12}$ (live carbon ratio)

1 year = 3.156×10^7 seconds

OpenStax Chapter 32 Equations - Applications of Nuclear Physics

Radiation doses:

absorbed dose = energy absorbed / mass affected ← SI unit = 1 gray = 1 Gy = 1 J/kg = 100 rad.

effective dose = absorbed dose × RBE ← SI unit = 1 sievert = 1 Sv = 1 J/kg = 100 rem.

RBE = relative biological effectiveness

RBE = QF = quality factor (units = Sv/Gy).

radiation:	γ-rays	slow β's	fast β's	slow neutrons	fast neutrons	protons	α's	heavy ions
RBE =	1	1.7	1	2–5	10	10	10–20	10–20

Reactions:

$Q = [M_{\text{reactants}} - M_{\text{products}}]c^2$ (reaction energy)

$Q > 0$ (Q = mass converted to energy)

$Q < 0$ ($|Q|$ = threshold energy)

Energy, power and mass in nuclear reactors:

$E = mc^2$ (Einstein's mass-energy equivalence)

$P = E/t$ (power)

$E = NQ$ [energy= (# of reactions)×(reaction energy)]

1 u $\cdot\ c^2$ = 931.5 MeV

$M = Nm$ [mass used= (# of reactions)×(reaction mass)]

$E_{\text{out}} = eE_{\text{in}}$ [output energy = (efficiency)×(input energy)]

Periodic Table of the Elements§

Symbol — Cl 17 — Atomic Number
Atomic Mass§ — 35.4527
Electron Configuration (outer shells only) — $3p^5$

Group I	Group II	Transition Elements										Group III	Group IV	Group V	Group VI	Group VII	Group VIII
H 1 1.00794 $1s^1$																	He 2 4.002602 $1s^2$
Li 3 6.941 $2s^1$	Be 4 9.012182 $2s^2$											B 5 10.811 $2p^1$	C 6 12.0107 $2p^2$	N 7 14.00674 $2p^3$	O 8 15.9994 $2p^4$	F 9 18.9984032 $2p^5$	Ne 10 20.1797 $2p^6$
Na 11 22.989770 $3s^1$	Mg 12 24.3050 $3s^2$											Al 13 26.981538 $3p^1$	Si 14 28.0855 $3p^2$	P 15 30.973761 $3p^3$	S 16 32.066 $3p^4$	Cl 17 35.4527 $3p^5$	Ar 18 39.948 $3p^6$
K 19 39.0983 $4s^1$	Ca 20 40.078 $4s^2$	Sc 21 44.955910 $3d^14s^2$	Ti 22 47.867 $3d^24s^2$	V 23 50.9415 $3d^34s^2$	Cr 24 51.9961 $3d^54s^1$	Mn 25 54.938049 $3d^54s^2$	Fe 26 55.845 $3d^64s^2$	Co 27 58.933200 $3d^74s^2$	Ni 28 58.6934 $3d^84s^2$	Cu 29 63.546 $3d^{10}4s^1$	Zn 30 65.39 $3d^{10}4s^2$	Ga 31 69.723 $4p^1$	Ge 32 72.61 $4p^2$	As 33 74.92160 $4p^3$	Se 34 78.96 $4p^4$	Br 35 79.904 $4p^5$	Kr 36 83.80 $4p^6$
Rb 37 85.4678 $5s^1$	Sr 38 87.62 $5s^2$	Y 39 88.90585 $4d^15s^2$	Zr 40 91.224 $4d^25s^2$	Nb 41 92.90638 $4d^45s^1$	Mo 42 95.94 $4d^55s^1$	Tc 43 (98) $4d^55s^2$	Ru 44 101.07 $4d^75s^1$	Rh 45 102.90550 $4d^85s^1$	Pd 46 106.42 $4d^{10}5s^0$	Ag 47 107.8682 $4d^{10}5s^1$	Cd 48 112.411 $4d^{10}5s^2$	In 49 114.818 $5p^1$	Sn 50 118.710 $5p^2$	Sb 51 121.760 $5p^3$	Te 52 127.60 $5p^4$	I 53 126.90447 $5p^5$	Xe 54 131.29 $5p^6$
Cs 55 132.90545 $6s^1$	Ba 56 137.327 $6s^2$	57–71†	Hf 72 178.49 $5d^26s^2$	Ta 73 180.9479 $5d^36s^2$	W 74 183.84 $5d^46s^2$	Re 75 186.207 $5d^56s^2$	Os 76 190.23 $5d^66s^2$	Ir 77 192.217 $5d^76s^2$	Pt 78 195.078 $5d^96s^1$	Au 79 196.96655 $5d^{10}6s^1$	Hg 80 200.59 $5d^{10}6s^2$	Tl 81 204.3833 $6p^1$	Pb 82 207.2 $6p^2$	Bi 83 208.98038 $6p^3$	Po 84 (209) $6p^4$	At 85 (210) $6p^5$	Rn 86 (222) $6p^6$
Fr 87 (223) $7s^1$	Ra 88 (226) $7s^2$	89–103‡	Rf 104 (261) $6d^27s^2$	Db 105 (262) $6d^37s^2$	Sg 106 (266) $6d^47s^2$	Bh 107 (264) $6d^57s^2$	Hs 108 (269) $6d^67s^2$	Mt 109 (268) $6d^77s^2$	Ds 110 (271) $6d^97s^1$	111 (272) $6d^{10}7s^1$	112 (277) $6d^{10}7s^2$						

†Lanthanide Series	La 57 138.9055 $5d^16s^2$	Ce 58 140.115 $4f^15d^16s^2$	Pr 59 140.90765 $4f^35d^06s^2$	Nd 60 144.24 $4f^45d^06s^2$	Pm 61 (145) $4f^55d^06s^2$	Sm 62 150.36 $4f^65d^06s^2$	Eu 63 151.964 $4f^75d^06s^2$	Gd 64 157.25 $4f^75d^16s^2$	Tb 65 158.92534 $4f^95d^06s^2$	Dy 66 162.50 $4f^{10}5d^06s^2$	Ho 67 164.93032 $4f^{11}5d^06s^2$	Er 68 167.26 $4f^{12}5d^06s^2$	Tm 69 168.93421 $4f^{13}5d^06s^2$	Yb 70 173.04 $4f^{14}5d^06s^2$	Lu 71 174.967 $4f^{14}5d^16s^2$
‡Actinide Series	Ac 89 (227.02775) $6d^17s^2$	Th 90 232.0381 $6d^27s^2$	Pa 91 (231) $5f^26d^17s^2$	U 92 238.0289 $5f^36d^17s^2$	Np 93 (237) $5f^46d^17s^2$	Pu 94 (244) $5f^66d^07s^2$	Am 95 (243) $5f^76d^07s^2$	Cm 96 (247) $5f^76d^17s^2$	Bk 97 (247) $5f^96d^07s^2$	Cf 98 (251) $5f^{10}6d^07s^2$	Es 99 (252) $5f^{11}6d^07s^2$	Fm 100 (257) $5f^{12}6d^07s^2$	Md 101 (258) $5f^{13}6d^07s^2$	No 102 (259) $5f^{14}6d^07s^2$	Lr 103 (262) $5f^{14}6d^17s^2$

§ Atomic mass values averaged over isotopes in the percentages they occur on Earth's surface. For unstable elements, mass of the longest-lived known isotope is given in parentheses. 2003 revisions. (See also Appendix B.)