Gen. Phys. II **Exam 5 - Chs. 30,31,32 - Atomic & Nuclear Physics** **May. 14, 2019**

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. Bonus points possible by correctly using prefixes like 2.0 mV, 7.8 MW, 1.6 kΩ, 3.4 μCi, etc., in lieu of scientific notation like 3.4×10^{-6} Ci.

OpenStax Ch. 30 - Atomic Physics.

1. (2) Cathode rays are now known to be a beam of

   a. atoms. b. nuclei. c. protons. d. neutrons. e. electrons.

2. (2) The scientist who is credited with first measuring the quantized charge of electrons was

   a. Amedeo Avogadro. b. Albert Einstein. c. Robert Millikan. d. Ernest Rutherford. e. J.J. Thomson.

3. (2) Niels Bohr assumed quantization of what physical quantity in order to arrive at the energy levels of hydrogen?

   a. angular momentum. b. electric charge. c. electron mass. d. nuclear mass.

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

4. (2) **T F** Bohr's model shows that hydrogen atoms generate a blackbody spectrum.
5. (2) **T F** In Bohr's model the atom's energy increases when the atom emits a photon.
6. (2) **T F** Bohr's model can predict the ionization energy of a hydrogenic atom or ion.

7. (12) Consider a hydrogen atom making some different transitions, as predicted using the Bohr model.

   a) (8) What is the longest wavelength of light that the atom can emit, starting from the $n = 3$ level?

   c) (4) What is the minimum energy of a photon that would ionize the atom, starting from the $n = 3$ level?

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

8. (2) How many electrons in an atom can have the set of quantum numbers, $n = 4, \ell = 4, m_\ell = 4$?

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9. (2) How many electrons in an atom can have the pair of quantum numbers, $n = 4, \ell = 3$?

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10. (4) Magnesium has the ground state electronic configuration, $1s^2 2s^2 2p^6 3s^2$. Give the values of the principal quantum number and the orbital quantum number for the highest energy electron.

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11. (2) For any atom, which one of these subshell configurations is not allowed?

a. $2p^3$ b. $3p^6$ c. $1s^1$ d. $4d^{11}$ e. $4f^7$

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12. (3) In the Zeeman effect, the 4f subshell is split into how many energy levels when a magnetic field is applied?

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

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13. (3) Which one of the following outer subshell configurations would correspond to a halogen, that tends to grab one electron from another atom?

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

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

1. (2) Nuclei with equal atomic numbers but different mass numbers are known as

   a. polymers. b. isomers. c. isotopes. d. nucleons. e. daughters.

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2. (2) For a stable nuclide of mass M, the total mass of its completely separated protons and neutrons is

   a. less than M. b. equal to M. c. greater than M.

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3. (4) How many protons and how many neutrons make up one ^{222}Rn (radon) nucleus?

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4. (2) For which type of decay process does the daughter nucleus have one more proton than the parent nucleus?

   a. α emission. b. β^- emission. c. β^+ emission. d. γ emission.

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5. (2) Which type of particle detector uses a saturated vapor to show particle tracks?

   a. Geiger counter. b. scintillation counter. c. cloud chamber. d. phosphorescent screen.

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6. (2) Generally speaking, which type of radiation from unstable nuclei is the most deeply penetrating?

   a. α radiation. b. β radiation. c. γ radiation.

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7. (2) Nitrogen-14 and nitrogen-15 are stable isotopes. How does ^{15}N differ from the more common ^{14}N?

   a. They have different numbers of protons. b. They have different numbers of electrons.
   c. They have different numbers of neutrons. d. Nitrogen-15 is radioactive, while nitrogen 14 is not.
   e. Both c & d are true.

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8. (2) **T F** After two half-lives, all the nuclei of a radioisotope sample have decayed.

9. (2) **T F** Barium-137m used in a class demo decays to barium-137 by gamma emission.

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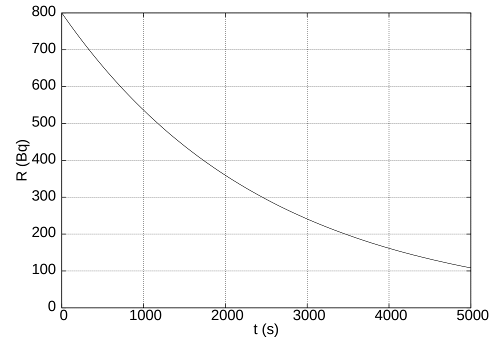
10. (6) An atom of helium-4 has a mass of 4.002603 u, while the much more rare helium-3 isotope has a mass of 3.016029 u. As you know, helium-4 has one more neutron (mass=1.008665 u) than helium-3. How much energy (in MeV) is required to **remove one neutron** from helium-4 and separate it into helium-3 and a free neutron? Hint: That is the binding energy of the neutron that is removed.

11. (8) A sample of a radioisotope with atom mass of 98.2 u has the activity shown, due to decays to a stable daughter nuclide.



a) (4) From the graph, estimate the half-life.

b) (4) How many nuclei are present at time $t = 0$?

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12. (8) You learned in class that natural carbon in living organisms has an activity of 0.25 Bq per gram of carbon. Carbon-14 decays with a half-life of 5730 years. Suppose a 12.0 gram sample of carbon in ancient wood currently has an activity of 0.88 Bq.

a) (4) About how strong was the activity in the 12.0 gram sample when the tree was alive?

c) (4) How much time has passed since the tree died, in years?

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

1. (2) Which of these radiation sources contributes the most low-level exposure in the United States?

a. radon. b. cosmic rays. c. medical x-rays. d. rocks, soil & food.

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2. (2) Biological damage from a 4 MeV α particle is worse than that from a 4 MeV β particle because

a. the α has twice the electric charge. b. the ions caused by the α occur over a larger region.
c. the ions caused by the α get larger charges. d. the ions caused by the α occur over a smaller region.

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3. (2) For equal energy particles from a source *inside* the body, which radiation produces the most severe cell damage?

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

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4. (2) For equal energy particles from a source *outside* the body, which radiation is most harmful to the human body?

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

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5. (2) **T F** ^{40}K is a source of internal background radiation for the human body.

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6. (2) Which isotopes could not be used as fuel for a fusion reactor? Check all that apply.

a. deuterium. b. helium-3. c. iron-56. d. uranium-235.

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7. (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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8. (8) A 65-kg worker is accidentally exposed to a beam of fast neutrons leaking from a malfunctioning nuclear reactor, with an average kinetic energy of 8.8 MeV. From a flux of 6.4×10^6 neutrons/second, 75% of them are absorbed in her body during a 1.00 hour exposure. Calculate the effective radiation dose in sieverts.

9. (4) Consider the reaction, $^2_1\text{H} + ^2_1\text{H} \rightarrow ^3_2\text{He} + X,$ 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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10. (4) Consider the reaction, $\text{n} + ^{239}_{94}\text{Pu} \rightarrow ^{137}_{55}Cs + ^{89}_{39}\text{Y} + X,$ 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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11. (12) The deuterium-deuterium (dd) reaction, $^2_1\text{H} + ^2_1\text{H} \rightarrow ^3_1\text{H} + ^1_1\text{H}$, releases an energy of $Q = 4.03$ MeV. Suppose this process powers a nuclear reactor by using all of the deuterium in a liter (1.00 kg) of water, where 0.0115 % of the hydrogen atoms are deuterium. The molar mass of water is 18.015 g/mol.

a) (6) By calculating the total number of ^2_1H in 1.00 kg of water, how many reactions will take place?

b) (6) If all the reactions are carried out in 24.0 hours, what is the power output of the reactor?

Prefixes

z=10^{-21},	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},	E=10^{18}, Z=10^{21}
zepto,	atto,	femto,	pico,	nano,	micro,	milli,	centi,	kilo,	mega,	giga,	tera,	peta,	exa, zeta

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 (1$^{\text{st}}$ 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 $m_s = -\frac{1}{2}, \ +\frac{1}{2}$
shell ($2n^2$ states) = a value of (n) is given.
orbital (2 states) = particular (n, l, m_l) are given.

$E_n = -(13.6 \text{ eV})/n^2$ (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)
sub-shell $[2(2\ell+1)$ states$]$ = values of (n, l) are given.
state = 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
$3p^5$ — Electron Configuration (outer shells only)

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.)