

APPENDIX C

DATA SUMMARIES

The measured values of fundamental constants become more accurately determined every year. Often, an improvement in the measurement of one particular constant changes the quoted value of another. The values quoted throughout Appendix C are from a self-consistent data set compiled in 1979. Other tabulations of constants and masses may vary from the tabulation used in this monograph.

C.I Units and Definitions

We work in the MKSA system in which

length is measured in *meters* (m)

mass is measured in *kilograms* (kg)

time is measured in *seconds* (s)

electric current is measured in *amperes* (A).

Other related units in the MKSA system are:

force is measured in *Newtons* (N): $1 \text{ N} = 1 \text{ kg}\cdot\text{m}/\text{s}^2$

energy is measured in *Joules* (J): $1 \text{ J} = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2$.

While these units are convenient for everyday terrestrial life, they are not very useful for subatomic studies. Two very small units of length are:

1 *nanometer* = 1 nm = 10^{-9} m (molecular length scale)

1 *fermi* = 1 fm = 10^{-15} m (nuclear length scale).

A unit of length that is typical of atomic dimensions is the Ångstrom (1 nm = 10^{-9} m = 10 Å). The length unit for nuclear dimensions, the fermi, is also called a *femtometer* and has the symbol fm. A quantity called a *barn*, which is equal to 100 fm², is used for nuclear areas.

Astronomy studies objects at very large distances. The distance that light travels in one year is a suitably large unit and is defined as a *light-year* (ly):

$$\begin{aligned} 1 \text{ light-year} &= [\text{speed of light}] \times [1 \text{ year}] \\ &= (3.00 \times 10^8 \text{ [m/s]}) \times (3.1557 \times 10^7 \text{ [s]}) \\ &= 9.46 \times 10^{15} \text{ m} = 9.46 \times 10^{12} \text{ km.} \end{aligned}$$

An astronomical length unit that arose from distance determinations using parallax is the parsec (pc), defined as 3.26 ly.

An ampere is defined as a *Coulomb* (C) of charge passing a point in 1 second. Rather than talk about the charge of the electron in terms of ampere-seconds, we define

$$e \text{ electron charge magnitude} = 1.602177 \times 10^{-19} \text{ C.}$$

The energy gained by a single electron when accelerated through a potential difference of 1 volt is defined as the *electron-volt*:

$$1 \text{ eV} \quad 1 \text{ electron-volt} \quad 1.602177 \times 10^{-19} \text{ J.}$$

For comparative purposes, we should also mention an energy unit called the calorie, which in terms of Joules is

$$1 \text{ cal} = 4.186 \text{ J.}$$

A *mole* is a quantity used extensively in chemistry to specify easily the number of atoms in a sample. While it might be tempting to define the mole as a nice simple number like 10^{23} , this turns out not to be very useful in the laboratory. Instead, one defines a mole of ¹²C atoms to have a mass of exactly 12.000 grams. Knowing the mass of a ¹²C atom, this means that a mole contains 6.022×10^{23} atoms, a number referred to as *Avogadro's number*. The usefulness of the mole is that the mass of a mole

of a given element, whose nucleus has a total of A protons and neutrons, is very close to A grams. As a trivial example, a mole of protons ($A = 1$) has a mass of 1.007 g, according to Table C.1. A mole of hydrogen atoms has very slightly more mass (1.008 g) due to the presence of one electron per proton. The *atomic mass* of an element is the mass in grams of a mole of the element, and is very close in value to the mass number A .

C.II Data Tabulations

Table C.1 Fundamental constants.

e	[<i>elementary charge</i>]	$1.6021892 \times 10^{-19}$ Coulombs
h	[<i>Planck's constant</i>]	6.626176×10^{-34} J-s
c	[<i>speed of light in vacuo</i>]	2.99792458×10^8 m/s
k	[<i>Coulomb constant</i>]	8.9876×10^9 Nm ² /C ²
G	[<i>gravitational constant</i>]	6.6720×10^{-11} m ³ kg ⁻¹ s ⁻²
m_e	[<i>electron mass</i>]	9.109×10^{-31} kg
m_p	[<i>proton mass</i>]	1.6726×10^{-27} kg
m_n	[<i>neutron mass</i>]	1.6750×10^{-27} kg
k_B	[<i>Boltzmann's constant</i>]	1.38×10^{-23} J/K ^o
N_o	[<i>Avogadro's number</i>]	6.022×10^{23} mol ⁻¹

Table C.2 Physical data.

<i>Mass of Earth</i>	5.98×10^{24} kg
<i>Mass of Moon</i>	7.36×10^{22} kg
<i>Mass of Sun</i>	1.99×10^{30} kg
<i>Radius of Earth</i>	6.37×10^6 m
<i>Radius of Moon</i>	1.74×10^6 m
<i>Radius of Sun</i>	6.96×10^8 m
<i>Earth-Moon distance</i>	3.84×10^8 m
<i>Earth-Sun distance</i>	1.50×10^{11} m
<i>Solar luminosity</i>	3.9×10^{26} J/s

Table C.3 Gauge bosons of the fundamental interactions. Each gauge boson is listed beside the fundamental interaction with which it is associated. The masses are quoted in both kg, and as mass energies mc^2 in $\text{GeV} = 10^9 \text{ eV}$. The existence of gluons and gravitons is inferred from experiment, but neither of these gauge bosons has been seen in isolation.

Symbol	Interaction	Mass (kg)	mc^2 (GeV)	J (spin)
g	strong	cannot be isolated		1
	electromagnetic	$< 5 \times 10^{-63}$	$< 3 \times 10^{-36}$	1
W^+, W^-	weak	$(1.44 \pm 0.007) \times 10^{-25}$	80.6 ± 0.4	1
Z^0	weak	1.63×10^{-25}	91.2	1
graviton	gravity	predicted to exist		2

Table C.4 Lepton family of elementary particles. The masses are quoted in both kg, and as mass energies mc^2 in $\text{MeV} = 10^6 \text{ eV}$.

Symbol	Mass (kg)	mc^2 (MeV)	J (spin)	L_e	L_μ	L
e	$< 3 \times 10^{-35}$	$< 17 \times 10^{-6}$	1/2	1	0	0
μ	$< 4.8 \times 10^{-31}$	< 0.27	1/2	0	1	0
	$< 6.2 \times 10^{-29}$	< 35	1/2	0	0	1
e^-	9.11×10^{-31}	0.511	1/2	1	0	0
μ^-	1.884×10^{-28}	105.7	1/2	0	1	0
τ^-	3.18×10^{-27}	1784 ± 3	1/2	0	0	1

Table C.5 Meson family of elementary particles. The masses are quoted as mass energies mc^2 . This is a *very* small sampling of the known mesons.

Symbol	mc^2 (MeV)	J (spin)	Charge states
π^0	135.0	0	0
π^+, π^-	139.6	0	+, -
	549	0	0
	768	1	+, 0, -
	782	1	0
η'	958	0	0
	1019	1	0 (anti- s s state)
η_c	2980	0	0 (anti- c c state)
	9460	1	0 (anti- b b state)
K	494	0	0, - (1 s -quark)
K*	892	1	0, - (1 s -quark)
D	1867	0	+, - (1 c -quark)
D _s	1969	0	+ (anti- c s state)
B	5278	0	0, - (1 b -quark)

Table C.6 Baryon family of elementary particles. The masses are quoted as mc^2 . This is a *very* small sampling of the known baryons.

Symbol	mc^2 (MeV)	J (spin)	Charge states	Strangeness
p, n	939	1/2	+, 0	0
N(1440)	1440	1/2	+, 0	0
N(1520)	1520	3/2	+, 0	0
N(1535)	1535	1/2	+, 0	0
(1232)	1232	3/2	++, +, 0, -	0
(1620)	1620	1/2	++, +, 0, -	0
(1700)	1700	3/2	++, +, 0, -	0
	1116	1/2	0	-1
	1190	1/2	+, 0, -	-1
	1320	1/2	0, -	-2
	1672	?	-	-3

Table C.7 Table of masses and binding energies given as a function of the number of protons Z and mass number A of the nucleus. The table gives the *atomic* mass defect $\Delta = m_{\text{ATOM}}(Z,A)c^2 - Am_0c^2$ of the neutral *atom*, where m_0c^2 is equal to 931.5016 MeV. The table also gives the binding energy per nucleon $B.E./A$, as determined from Δ . For each element (specified by Z) the values of A chosen include the most abundant isotope or the isotope that is longest lived. For the purposes of this monograph, $B.E./A$ is quoted to sufficient accuracy to allow the calculation of Q -values. The mass energies of the proton and neutron are $m_p c^2 = 938.280$ and $m_n c^2 = 939.573$ MeV, respectively.

Z	A	<i>Element</i>	Δ (MeV)	$B.E./A$ (MeV)
0	1	n	8.0714	0
1	1	H	7.289	0
1	2	H	13.1358	1.1123
1	3	H	14.9499	2.8273
2	3	He	14.9319	2.5725
2	4	He	2.4249	7.0740
3	7	Li	14.9068	5.6065
4	8	Be	4.9417	7.0625
4	9	Be	11.3477	6.4628
5	11	B	8.668	6.9278
6	12	C	0.0	7.6802
6	13	C	3.125	7.4699
7	13	N	5.3455	7.2389
7	14	N	2.8634	7.4757
7	15	N	0.1015	7.6995
8	15	O	2.8555	7.4638
8	16	O	-4.737	7.9763
9	19	F	-1.4874	7.7791
10	20	Ne	-7.0462	8.0325
11	23	Na	-9.5314	8.1116
12	24	Mg	-13.9331	8.2607
13	27	Al	-17.1968	8.3316
14	28	Si	-21.4924	8.4478
15	31	P	-24.4407	8.4812
16	32	S	-26.0162	8.4932
17	35	Cl	-29.0137	8.5203

18	40	Ar	-35.0396	8.5953
19	39	K	-33.8066	8.5571
20	40	Ca	-34.8469	8.5514
21	45	Sc	-41.0579	8.6187
22	48	Ti	-48.4871	8.7229
23	51	V	-52.1997	8.7421
24	52	Cr	-55.4152	8.7760
25	55	Mn	-57.7092	8.7650
26	56	Fe	-60.6041	8.7904
27	59	Co	-62.2265	8.7680
28	58	Ni	-60.2251	8.7321
29	63	Cu	-65.5787	8.7522
30	64	Zn	-66.0017	8.7359
31	69	Ga	-69.3225	8.7246
32	74	Ge	-73.4234	8.7253
33	75	As	-73.0351	8.7009
34	80	Se	-77.7621	8.7109
35	79	Br	-76.07	8.6877
36	84	Kr	-82.431	8.7174
36	92	Kr	-68.68	8.5118
37	85	Rb	-82.1644	8.6975
38	88	Sr	-87.9162	8.7326
39	89	Y	-87.7022	8.7140
40	90	Zr	-88.7697	8.7100
41	93	Nb	-87.2098	8.6642
42	98	Mo	-88.1132	8.6352
43	98	Tc	-86.429	8.6100
44	104	Ru	-88.098	8.5875
45	103	Rh	-88.027	8.5842
46	106	Pd	-89.91	8.5801
47	107	Ag	-88.407	8.5540
48	114	Cd	-90.0229	8.5316
49	115	In	-89.534	8.5166
50	120	Sn	-91.1017	8.5046
51	121	Sb	-89.5907	8.4820
52	130	Te	-87.348	8.4303
53	127	I	-88.984	8.4455
54	132	Xe	-89.29	8.4278
55	133	Cs	-88.093	8.4102
56	138	Ba	-88.276	8.3936

56	141	Ba	-79.771	8.3264
56	145	Ba	-68.04	8.2385
57	139	La	-87.238	8.3782
58	140	Ce	-88.089	8.3765
59	141	Pr	-86.027	8.3541
60	142	Nd	-85.959	8.3462
61	145	Pm	-81.28	8.3028
62	152	Sm	-74.773	8.2442
63	153	Eu	-73.379	8.2288
64	158	Gd	-70.702	8.2020
65	159	Tb	-69.544	8.1889
66	164	Dy	-65.977	8.1588
67	165	Ho	-64.908	8.1471
68	166	Er	-64.935	8.1421
69	169	Tm	-61.282	8.1146
70	174	Yb	-56.953	8.0840
71	175	Lu	-55.173	8.0692
72	180	Hf	-49.7928	8.0351
73	181	Ta	-48.445	8.0235
74	184	W	-45.71	8.0052
75	187	Re	-41.224	7.9781
76	192	Os	-35.893	7.9486
77	193	Ir	-34.543	7.9382
78	195	Pt	-32.821	7.9268
79	197	Au	-31.165	7.9158
80	202	Hg	-27.37	7.8970
81	205	Tl	-23.846	7.8786
82	208	Pb	-21.772	7.8676
82	210	Pb	-14.752	7.8361
83	209	Bi	-18.282	7.8482
83	214	Bi	-1.219	7.7736
84	209	Po	-16.391	7.8354
84	214	Po	-4.494	7.7853
85	210	At	-11.992	7.8118
86	222	Rn	16.367	7.6946
87	223	Fr	18.381	7.6837
88	226	Ra	23.6626	7.6620
89	227	Ac	25.849	7.6508
90	232	Th	35.4444	7.6151
90	234	Th	40.607	7.5969

91	231	Pa	33.4222	7.6185
92	235	U	40.9155	7.5910
92	238	U	47.306	7.5702
93	237	Np	44.8683	7.5751
94	244	Pu	59.801	7.5249
95	243	Am	57.171	7.5303
96	247	Cm	65.528	7.5020
97	247	Bk	65.485	7.4990
98	249	Cf	69.7179	7.4835
99	252	Es	77.263	7.4574
100	257	Fm	88.585	7.4223
101	258	Md	91.82	7.4092
102	259	No	94.018	7.4003
103	260	Lr	98.1	7.3841

Further Reading

Table of Isotopes (Wiley, New York, ed. 7, 1978).

Review of Particle Properties, Physical Review D45, number 11-II (1992).

APPENDIX D

ANSWERS TO ODD-NUMBERED PROBLEMS

Chap. 1

1. (a) $5 \times 10^{12} \text{ m}^2$; (b) 0.0098
3. 1200 litres
5. 10^{10} particles per second
7. 60 seconds
9. Nucleus: $2.3 \times 10^{17} \text{ kg/m}^3$; Earth: $5.50 \times 10^3 \text{ kg/m}^3$; Sun: $1.41 \times 10^3 \text{ kg/m}^3$
11. (a) 2.0×10^{-6} ; (b) 9,800 yrs
13. (a) $(4/3)^{-1/3}L$; (b) 0.827
15. 5.8×10^{-20}
17. Aluminum: 2.5×10^{-5} ; gold: 9.0×10^{-5}
19. 176,000 light years

Chap. 2

1. Electrostatic: $8.8 \times 10^{-8} \text{ N}$; gravitational: $3.9 \times 10^{-47} \text{ N}$
3. 10^{-10}
5. strong interaction
7. $1.7 \times 10^{-29} \text{ m}^2$
9. B, L_e, Q (a) 0, 0, -1; (b) 1, 0, (+1 or 0); (c) 1, 0, +1; (d) -1, 0, 0.
11. (a) $J = 1/2$, fermion; (b) $J = 1/2$, fermion; (c) $J = 1$, boson; (d) $J = 0$, boson; (e) $J = 3/2$, fermion.
13. (a) $8.6 \times 10^{-11} \text{ C/kg}$; (b) $1.44 \times 10^{-37} \text{ C}$; (c) 9×10^{-19}

Chap. 3

1. (a) $3.9 \times 10^5 \text{ kg-m}^2/\text{s}^2$; (b) $4.9 \times 10^{15} \text{ kg-m}^2/\text{s}^2$
3. $(5/3)c$
5. (a) $1.0 \times 10^{-27} \text{ kg-m/s}$; (b) 3×10^{27} photons
7. (a) $1.2 \text{ } \mu\text{m}$; (b) $1.2 \times 10^{-3} \text{ nm}$; (c) 1.2 fm

9. (a) $5.95 \times 10^8 \text{ kg-m/s}^2$; (b) $3.5 \times 10^{22} \text{ kg-m/s}^2$
 11. (a) $5.95 \times 10^5 \text{ m/s}$; (b) 0 m/s
 13. (a) $6.6 \times 10^{-25} \text{ kg-m/s}$; $2.4 \times 10^{-19} \text{ J}$
 (b) $3.3 \times 10^{-24} \text{ kg-m/s}$; $6.0 \times 10^{-18} \text{ J}$
 15. (a) photons: $9.94 \times 10^{-16} \text{ J}$; neutrons: $3.28 \times 10^{-21} \text{ J}$
 (b) photons: $7.2 \times 10^7 \text{ }^\circ\text{K}$, very high energy source; neutrons: $238 \text{ }^\circ\text{K}$, room temperature source
 17. (a) 9.4 eV ; (b) 22.8 MeV ; (c) 496 MeV
 19. (a) 410 MeV ; (b) 86 MeV

Chap. 4

1. 1875.7 MeV
 3. (a) $3.8 \times 10^{28} \text{ J}$; (b) $5.5 \times 10^{41} \text{ J}$
 5. $4.4 \times 10^9 \text{ kg loss}$
 7. (a) $2.49 \times 10^{15} \text{ kg}$; (b) $5.09 \times 10^{22} \text{ kg}$
 9. $3.7 \times 10^{27} \text{ kg}$
 11. 297
 13. $1.2 \times 10^{-12} \text{ kg}$
 15. $1.25 \times 10^{29} \text{ J}$
 17. (a) and (c) forbidden; (b) allowed
 19. (a) 135.0 MeV ; (b) $3.6 \times 10^{-20} \text{ kg-m/s}$; (c) 18 fm

Chap. 5

1. (a) strong; (b) electromagnetic; (c) weak; (d) electromagnetic
 3. (a) weak; (b) strong; (c) electromagnetic; (d) strong;
 lifetimes: $a > c > (b,d)$
 5. (a) lepton number; (b) charge, lepton number; (c) baryon number
 7. (a) $\bar{n} \quad \bar{p} + e^+ + e^-$; (b) $n \quad e^- + \bar{p}$;
 (c) $\bar{p} + e^+$ or $\bar{p} + e^-$; (d) $e^+ + e^-$
 9. (B, Q) of quark states: $(uuu)(1,+2)$; $(uud)(1,+1)$; $(uus)(1,+1)$; $(udd)(1,0)$;
 $(uds)(1,0)$; $(uss)(1,0)$; $(ddd)(1,-1)$; $(dds)(1,-1)$; $(dss)(1,-1)$; $(sss)(1,-1)$;
 masses: $(sss) > (uss, dss) > (uus, uds, dds) > (uuu, uud, udd, ddd)$
 11. (a) $C = 410 \text{ N}$; (b) $2.0 \times 10^{-13} \text{ J}$
 13. (a) W^+ ; (b) Z^0 ; (c) gluon; (d) Z^0

Chap. 6

1. (a) -0.092 MeV, not spontaneous; (b) 7.367 MeV, spontaneous
(c) 2.225 MeV, spontaneous; (d) 161.74 MeV, spontaneous
(e) 0.764 MeV, spontaneous
3. (i) 1.944 MeV; (ii) 1.199 MeV; (iii) 7.551 MeV; (iv) 7.297 MeV;
(v) 1.732 MeV; (vi) 4.966 MeV; total = 24.687 MeV
5. (a) ^{234}Th ; (b) ^2H ; (c) ^{234}U ; (d) e^- ; (e)
7. 1.4 sec
9. (a) 1.2×10^{18} decays/sec; (b) $4.6 \times 10^{-17}\%$
11. 1.6 days
13. (a) 468.8 MeV; (b) 9.97×10^{57} MeV; (c) 1.29×10^{11} yrs
15. No, the predicted count rate is 9.5 min^{-1}
17. (a) 1.51×10^{-10} J/s; (b) $1.06 \times 10^{27} \lambda$ [J/m²-time]; (c) $1.32 \times 10^{-24} \text{ s}^{-1}$;
(d) 2.4×10^{16} yrs
19. Formula: ^{20}Ne 160.9 MeV; ^{40}Ar 361.3 MeV; ^{127}I 1174.9 MeV
Measured: ^{20}Ne 160.7 MeV; ^{40}Ar 343.8 MeV; ^{127}I 1072.6 MeV

Chap. 7

1. proof
3. 22 ly
5. 0.014 watts/m² from Moon vs. 1400 watts/m² from Sun

Chap. 8

1. (a) 578 s^{-1} ; (b) 460 s^{-1}
3. (a) 1.5×10^7 m/s; (b) 70 km/s-Mpc, acceptable
5. $0.72c$
7. 0.5 sec^{-1}

Chap. 9

1. $2 \times 10^{25} \text{ }^\circ\text{K}$
3. (a) $1.90 \times 10^{12} \text{ }^\circ\text{K}$; (b) 7.1×10^{-11} J; (c) 55 times nuclear *B.E./A*
5. (a) 260 m/s; (b) 1.5×10^{-9} m

Chap. 10

1. (a) $6.0 \times 10^{11} \text{ }^\circ\text{K}$; (b) $2.2 \times 10^9 \text{ }^\circ\text{K}$; (c) $4.0 \times 10^{12} \text{ }^\circ\text{K}$
3. (a) 7.6×10^{20} J/m³; (b) $2.2 \times 10^{-3} \text{ s}^{-1}$; (c) 7.7 min.
5. 10^{-1300}

Chap. 11

1. (a) 0.401 MeV; (b) $1.8 \times 10^{38} \text{ s}^{-1}$; (c) $6.5 \times 10^{10} \text{ cm}^{-2}\text{s}^{-1}$
3. (i) 7.162 MeV; (ii) 4.734 MeV; (iii) 9.312 MeV; (iv) 9.984 MeV;
 $Q/A = 1.114 \text{ MeV}$
5. (a) (i) 38.4 N; (ii) 47.7 N; (iii) 274 N; (iv) 99.3 N; (v) 128 N
(b) (i) $6.4 \times 10^9 \text{ }^\circ\text{K}$; (ii) $7.2 \times 10^9 \text{ }^\circ\text{K}$; (iii) $7.3 \times 10^{10} \text{ }^\circ\text{K}$;
(iv) $2.1 \times 10^{10} \text{ }^\circ\text{K}$; (v) $2.9 \times 10^{10} \text{ }^\circ\text{K}$; (c) required temp $i < ii < iv < v < iii$

APPENDIX E**SAMPLE QUIZ AND MIDTERM EXAM**

The following pages contain a quiz and midterm exam used in 1993. The quiz was written after lecture #5 while the midterm was written after the modern physics lectures were finished (lecture #12). The average mark on the quiz was 62%, and the average mark on the midterm was 64%. (The marks are scaled at the end of term to give a letter grade.)

PHYSICS 120 QUIZ

Time: 25 Minutes

Calculator and one formula sheet allowed

Some useful formulae:

[area of disk] = R^2

[area of sphere] = $4 R^2$

[volume of sphere] = $(4/3)R^3$

$c = 3.0 \times 10^8$ m/s

[proton mass] = 1.67×10^{-27} kg

[electron mass] = 9.11×10^{-31} kg

Circle one answer in each of the following questions:

1. What quantum number is violated by the reaction $e^+ + e^- \rightarrow e^+ + ?$

- (a)
- L_e
- (b)
- B
- (c)
- Q
- (d) none of (a-c)

2. A proton detector of diameter 10 cm is placed 20 cm away from a radioactive source of energetic protons. What is the probability that a proton leaving the source in a random direction actually passes into the detector?

- (a)
- 10^{-32}
- (b)
- 10^{-30}
- (c)
- 1.6×10^{-2}
- (d) 0.0625 (e)
- 6×10^{-34}

3. What is the approximate cross section for the reaction $p + e^+ \rightarrow p + e^+$?

- (a)
- 1 fm^2
- (b)
- 10^{-42} m^2
- (c)
- 10^{-24} m^2
- (d)
- 10^{-36} m^2
- (e)
- 10^{-16} m^2

4. A country decides to make several different coins of aluminum in the shape of disks with the same thickness. How do the radii of the coins vary with the mass M of the coin?

- (a) no change (b)
- $M^{1/2}$
- (c)
- $M^{1/3}$
- (d)
- M^1
- (e) none of (a-d)

5. A flashlight battery delivers 3 Joules of energy per second to a lightbulb that then radiates the light away. What is the change in mass of the battery per second while it delivers this energy?

- (a) 0 (b) 3 kg gain (c)
- 3×10^{-17}
- kg gain (d)
- 10^{-8}
- kg loss
-
- (e)
- 3×10^{-17}
- kg loss

PHYSICS 120 MIDTERM EXAM

Time: 50 Minutes

Calculator and one formula sheet allowed

Some useful constants:

$$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$$

$$c = 3.0 \times 10^8 \text{ m/s}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

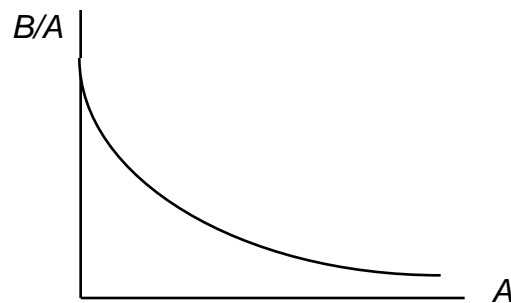
$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$[\text{electron mass}] = 9.11 \times 10^{-31} \text{ kg}$$

1. Circle one answer in each of the following questions:

(i) Suppose that the binding energy per nucleon curve for the most deeply bound nuclei had the form shown in the figure. What reaction/decays would be allowed for such nuclei?

- (a) fission forbidden
- (b) fission allowed for all A
- (c) fusion forbidden in all reactions
- (d) fusion allowed for small A only
- (e) fission allowed only for large A , fusion allowed for small A



(ii) The decay rate of a sample decreases from 6 Ci to 3 Ci in one minute. What fraction of the initial particles are left after 2 minutes?

- (a) 1
- (b) none
- (c) 1/2
- (d) 1/4
- (e) need N_0 to find answer

(iii) If the temperature inside an oven increases from 0 °C (i.e., 273 °K) to 273 °C, what is the ratio of the new photon number density divided by the original photon number density?

- (a) 4
- (b) 1
- (c) 8
- (d) 2
- (e) 16

(iv) If two nuclei have the same mass number and binding energy, they must have the same

- (a) Q (b) atomic number (c) mass (d) N (e) baryon number

(v) A particle of mass M_1 decays into two identical particles of mass M_2 each. If the Q -value for the decay is Q , what is M_2 ?

- (a) $(M_1 - Q/c^2)/2$ (b) $(M_1/2) - Q/c^2$ (c) $M_1 - Q$
(d) $(M_1 - Q)/2$ (e) $(M_1 c^2 - Q)/2$

2. Suppose that the work function of a metal is negligibly small compared to the energy of an incoming photon and outgoing electron in a photoelectric experiment.

- (a) What is the maximum kinetic energy of a photoelectron emitted when yellow light ($f = 5 \times 10^{14} \text{ s}^{-1}$) strikes this particular metallic surface?
(b) What is the de Broglie wavelength of the electron?
(c) Is the de Broglie wavelength less than the photon wavelength?

3. Blue light ($\lambda = 400 \text{ nm}$) from a nearby star is observed on Earth to be shifted to shorter wavelengths by 1 nm. What is the star's apparent velocity (including direction) with respect to the Earth?