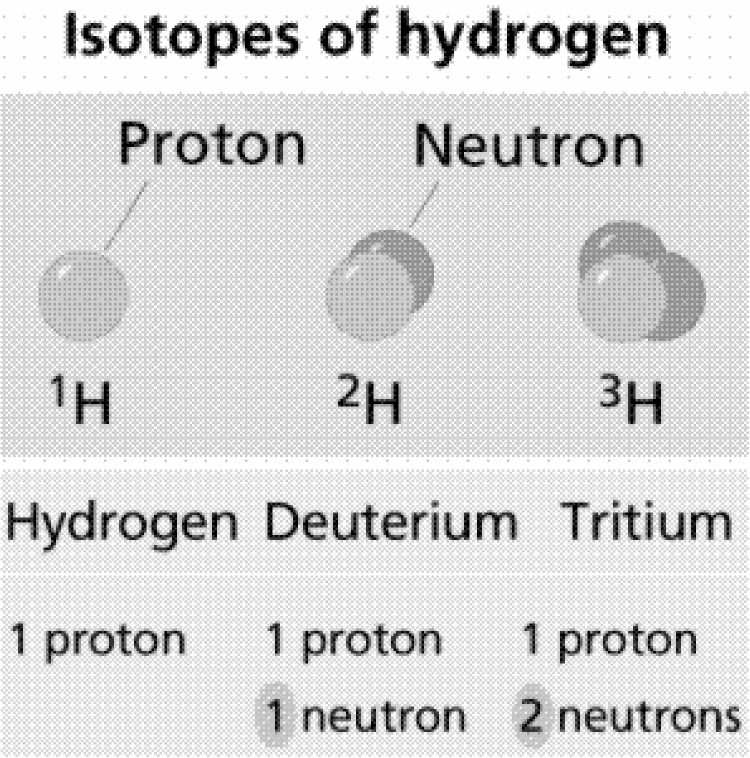
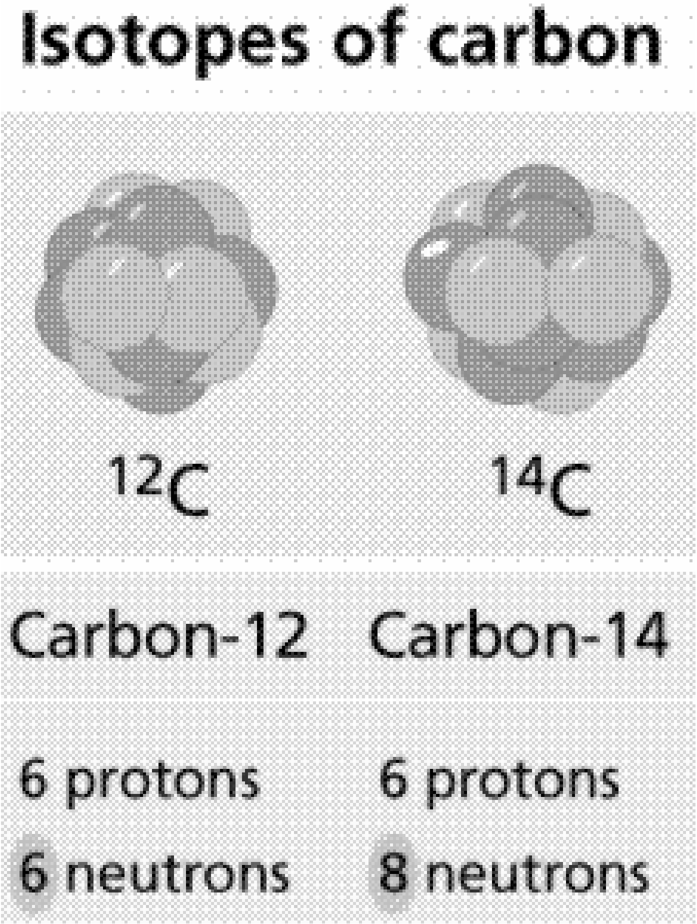
The Mole

- The amount of gas in a given volume is conveniently expressed in terms of the number of moles
- One **mole** of any substance is that amount of the substance that contains **Avogadro’s number** of constituent particles
  - Avogadro’s number $\boldsymbol{N_A = 6.022 \times 10^{23}}$
  - The constituent particles can be atoms or molecules

Got mole problems? Call Advogadro at 602-1023

In many problems it is better to work with lump numbers of molecules!





THE MOLE UNIT

Atomic Weight is defined as the mass of one atom of an element.

The first element, which has been assigned a mass was the **carbon-12** atom, and it was said to be exactly 12 amu (atomic mass units).

Using the carbon 12 atom as a basis for all the other atoms, proportions were set up and atomic weights were assigned to each of the other atoms.

Atomic weights can be looked up on the **periodic table** and they are the larger numbers in each box.

THE MOLE UNIT

The mole is defined as **the number of** carbon-12 **atoms** in 12 grams of carbon-12.

1 mole (**of any substance**) = 6.022×10^{23} **atoms, molecules, or ions** (depending on how that substance exists at that time.) (For example, 1 mole of Xe^+ ions has 6.022×10^{23} Xe^+ ions in it.)

1 mole (of any substance) = the total of the elements atomic **masses expresses in grams**. (For example, 1 mole of Na weighs 23 grams.)

The mole allows to **weigh** substances **and** to tell **how many particles** are in that substance.

PERIODIC TABLE OF THE ELEMENTS

Table of Selected Radioactive Isotopes

$_{0}$n	1	(15.3 min) β^-
$_{1}$H	3	(12.26 y) β^-
$_{4}$Be	7	(53.3 d) EC
	10	(1.6×10^6 y) β^-
$_{6}$C	11	(20.40 min) β^+
	14	(5730 y) β^-
$_{9}$F	18	(109.8 min) β^+
$_{11}$Na	22	(2.602 y) β^+, EC
	24	(15.02 h) β^-
$_{12}$Mg	28	(20.9 h) β^-
$_{13}$Al	26	(7.2×10^5 y) β^+, EC
$_{15}$P	32	(14.26 d) β^-
$_{16}$S	35	(87.2 d) β^-
$_{17}$Cl	36	(3.01×10^5 y) β^-
	38	(37.2 min) β^-
$_{18}$Ar	37	(35.02 d) EC
	39	(265 y) β^-
$_{19}$K	40	(1.28×10^9 y) EC
	42	(12.36 h) β^-
$_{20}$Ca	45	(165 d) β^-
$_{21}$Sc	46	(83.80 d) β^-
$_{24}$Cr	51	(27.70 d) EC
$_{25}$Mn	53	(2×10^6 y) EC
	54	(313.0 d) EC
	56	(2.578 h) β^-
$_{26}$Fe	59	(44.6 d) β^-
$_{27}$Co	56	(78.8d) β^+, EC
	57	(270 d) EC
	58	(71.3 d) β^+, EC
	60	(5.272 y) β^-
$_{28}$Ni	57	(36.0 h) β^+, EC
	59	(8×10^4 y) EC
	63	(92 y) β^-
$_{29}$Cu	64	(12.70 h) β^-, β^+, EC
	67	(61.88 h) β^-
$_{30}$Zn	65	(244.1 d) β^+, EC
$_{31}$Ga	67	(78.2 h) EC
	72	(14.10 h) β^-
$_{32}$Ge	68	(275 d) EC
$_{33}$As	73	(80.3 d) EC
	74	(17.9 d) β^-, β^+, EC
$_{34}$Se	75	(118.5 d) β^-
	79	(6.5×10^4 y) β^-
$_{35}$Br	82	(35.34 h) β^-
$_{36}$Kr	81	(2.1×10^5 y) EC
	85	(10.72 y) β^-
$_{37}$Rb	86	(18.7 d) β^-
	87	(4.8×10^{10} y) β^-
$_{38}$Sr	90	(28.8 y) β^-
$_{39}$Y	88	(106.6 d) β^+, EC
$_{40}$Zr	93	(1.5×10^6 y) β^-
	95	(64.0 d) β^-
$_{41}$Nb	94	(2.0×10^4 y) β^-
	95	(35.15 d) β^-
$_{42}$Mo	99	(66.02 h) β^-
$_{43}$Tc	97	(2.6×10^6 y) EC
	98	(4.2×10^6 y) β^-
	99	(2.13×10^5 y) β^-
$_{44}$Ru	106	(367 d) β^-
$_{45}$Rh	101	(3.3 y) EC
$_{46}$Pd	103	(17.0 d) EC
	107	(7×10^6 y) β^-
$_{47}$Ag	108	(127 y) EC
	110	(252 d) β^-
	111	(7.45 d) β^-
$_{48}$Cd	109	(453 d) EC
$_{49}$In	114	(49.51 d) IT
$_{50}$Sn	121	(76 y) β^-
$_{51}$Sb	124	(60.20 d) β^-
	125	(2.7 y) β^-
$_{52}$Te	121 m	(154 d) IT
	123 m	(119.7 d) IT
	127 m	(109 d) IT
$_{53}$I	129	(1.6×10^7 y) β^-
	131	(8.040 d) β^-
$_{54}$Xe	133	(5.25 d) β^-
	135	(9.10 h) β^-
$_{55}$Cs	134	(2.06 y) β^-
	135	(2.9×10^6 y) β-
	137	(30.17 y) β^-
$_{56}$Ba	140	(12.8 d) β^-
$_{57}$La	137	(6×10^4 y) EC
	140	(40.3 h) β^-
$_{58}$Ce	144	(284 d) β^-
$_{59}$Pr	142	(19.1 h) β^-
$_{60}$Nd	147	(11.1 d) β^-
$_{61}$Pm	145	(18 y) EC
	147	(2.62 y) β^-
$_{62}$Sm	146	(7×10^7 y) α
	151	(93 y) β^-
$_{63}$Eu	152	(13 y) β^+, EC, β^-
	154	(8.5 y) β^-
$_{64}$Gd	150	(2.1×10^6 y) α
$_{65}$Tb	158	(1.2×10^2 y) EC, β^-
	160	(72.3 d) β^-
$_{67}$Ho	166 m	(1.2×10^3 y) β^-
$_{69}$Tm	170	(128.6 d) β^-
	171	(1.92 y) β^-
$_{70}$Yb	169	(32.0 d) EC
	175	(4.19 d) β^-
$_{71}$Lu	176	(3.7×10^{10} y) β^-
$_{73}$Ta	182	(115.0 d) β^-
$_{74}$W	181	(140 d) EC
	185	(75.1 d) β^-
	188	(69 d) β^-
$_{75}$Re	187	(5×10^{10} y) β^-
$_{76}$Os	194	(6.0 y) β^-
$_{77}$Ir	192	(74.2 d) β^-, β^+, EC
$_{79}$Au	195	(183 d) EC
	196	(6.18 d) β^+, EC, β^-
	198	(2.696 d) β^-
	199	(3.15 d) β^-
$_{80}$Hg	203	(46.8 d) β^-
$_{81}$Tl	204	(3.77 y) β^-
$_{82}$Pb	202	(3×10^5 y) EC
	205	(3×10^7 y) EC
	210	(22.3 y) β^-, α
$_{83}$Bi	207	(38 y) EC
	208	(3.7×10^5 y) EC
	210	(5.01 d) β^-, α
	210 m	(3×10^6 y) α
$_{84}$Po	208	(2.90 y) α
	209	(102 y) α
	210	(138.38 d) α
$_{85}$At	209	(5.4 h) EC, α
	210	(8.1 h) EC
	211	(7.21 h) EC, α
$_{86}$Rn	222	(3.824 d) α
$_{87}$Fr	212	(19.3 min) EC, α
	222	(15 min) β^-
	223	(21.8 min) β^-
$_{88}$Ra	226	(1.60×10^3 y) α
$_{89}$Ac	227	(21.77 y) β^-
$_{90}$Th	228	(1.913 y) α
	230	(7.7×10^4 y) α
	232	(1.40×10^{10} y) α
$_{91}$Pa	231	(3.28×10^4 y) α
$_{92}$U	233	(1.59×10^5 y) α
	234	(2.44×10^5 y) α
	235	(7.04×10^8 y) α
	236	(2.34×10^7 y) α
	238	(4.47×10^9 y) α
$_{93}$Np	236	(1.1×10^5 y) EC, β^-
	237	(2.14×10^6 y) α
	239	(2.346 d) β^-
$_{94}$Pu	238	(87.75 y) α
	239	(2.41×10^4 y) α
	240	(6.54×10^3 y) α
	242	(3.8×10^5 y) α
	244	(8.3×10^7 y) α
$_{95}$Am	241	(432 y) α
	243	(7.37×10^3 y) α
$_{96}$Cm	242	(163.2 d) α
	244	(18.12 y) α
	247	(1.55×10^7 y) α
	248	(3.5×10^5 y) α, SF
$_{97}$Bk	247	(1.4×10^3 y) α
$_{98}$Cf	249	(351 y) α
	251	(900 y) α
$_{99}$Es	252	(472 d) α
	253	(20.47 d) α
	254	(276 d) α
$_{100}$Fm	255	(20.1 h) α
	257	(100.5 d) α
$_{101}$Md	258	(55 d) α
$_{102}$No	259	(58 min) α
$_{103}$Lr	260	(3.0 min) α
$_{104}$Rf	261	(65 s) α
$_{105}$Db	262	(40 s) α
$_{106}$Sg	263	(0.9 d) α

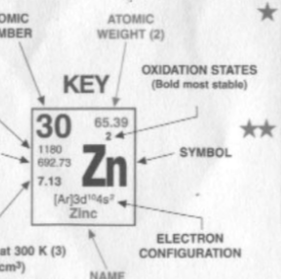
Selected Radioactive Isotopes

Naturally occurring radioactive isotopes are designated by a mass number in blue (although some are also manufactured). Letter m indicates an isomer of another isotope of the same mass number. Half-lives follow in parentheses, where s, min, h, d, and y stand respectively for seconds, minutes, hours, days, and years. The table includes mainly the longer-lived radioactive isotopes; many others have been prepared. Isotopes known to be radioactive but with half-lives exceeding 10^{12} y have not been included. Symbols describing the principal mode (or modes) of decay are as follows (these processes are generally accompanied by gamma radiation):

α	alpha particle emission
β^-	beta particle (electron) emission
β^+	positron emission
EC	orbital electron capture
IT	isomeric transition from upper to lower isomeric state
SF	spontaneous fission

ROUP 1/IA	2/IIA	3/IIIA	4/IVA	5/VA	6/VIA	7/VIIA	8	9 VIIIA	10	11/IB	12/IIB	13/IIIB	14/IVB	15/VB	16/VIB	17/VIIB	18/VI
1.00794 1 8 1 399 † H $1s^1$ Hydrogen																	2 4.0 4.216 0.95 at 26 atm 0.1785† H $1s^2$ Heliun
6.941 1 5 7 3 Li $1s^2 2s^1$ Lithium	4 9.01218 2 3243 1560 1.85 Be $1s^2 2s^2$ Beryllium											5 10.811 3 4275 2365 2.34 B $1s^2 2s^2 p^1$ Boron	6 12.011 ±4,2 5100* 3825* 2.26 C $1s^2 2s^2 p^2$ Carbon	7 14.0067 ±3,5,4,2 77.344 63.15 1.251† N $1s^2 2s^2 p^3$ Nitrogen	8 15.9994 -2 90.188 54.8 1.429† O $1s^2 2s^2 p^4$ Oxygen	9 18.99840 -1 85.0 53.55 1.696† F $1s^2 2s^2 p^5$ Fluorine	10 20. 27.10 24.55 0.900† N $1s^2 2s^2$ Neon
1 22.98977 1 6 0 7 Na [Ne]$3s^1$ Sodium	12 24.305 2 1380 922 1.74 Mg [Ne]$3s^2$ Magnesium											13 26.98154 3 2740 933.5 2.70 Al [Ne]$3s^2 p^1$ Aluminum	14 28.0855 4,2 2630 1683 2.33 Si [Ne]$3s^2 p^2$ Silicon	15 30.97376 ±3,5,4 553 317.3 1.82 P [Ne]$3s^2 p^3$ Phosphorus	16 32.066 ±2,4,6 717.82 392.2 2.07 S [Ne]$3s^2 p^4$ Sulfur	17 35.4527 ±1,3,5,7 239.18 172.17 3.214† Cl [Ne]$3s^2 p^5$ Chlorine	18 39 87.45 83.95 1.784† A [Ne]$3s^2$ Argon
9 39.0983 1 3 8 6 K [Ar]$4s^1$ otassium	20 40.078 2 1757 1112 1.55 Ca [Ar]$4s^2$ Calcium	21 44.9559 3 3109 1814 2.99 Sc [Ar]$3d^1 4s^2$ Scandium	22 47.87 4,3 3560 1935 4.54 Ti [Ar]$3d^2 4s^2$ Titanium	23 50.9415 5,4,3,2 3650 2163 6.11 V [Ar]$3d^3 4s^2$ Vanadium	24 51.996 6,3,2 2945 2130 7.19 Cr [Ar]$3d^5 4s^1$ Chromium	25 54.9380 7,6,4,2,3 2235 1518 7.44 Mn [Ar]$3d^5 4s^2$ Manganese	26 55.845 2,3,6 3023 1808 7.874 Fe [Ar]$3d^6 4s^2$ Iron	27 58.9332 2,3 3143 1768 8.90 Co [Ar]$3d^7 4s^2$ Cobalt	28 58.6934 2,3 3005 1726 8.90 Ni [Ar]$3d^8 4s^2$ Nickel	29 63.546 2,1 2840 1356.6 8.96 Cu [Ar]$3d^{10} 4s^1$ Copper	30 65.39 2 1180 692.73 7.13 Zn [Ar]$3d^{10} 4s^2$ Zinc	31 69.723 3 2478 302.92 5.91 Ga [Ar]$3d^{10} 4s^2 p^1$ Gallium	32 72.61 4 3107 1211.5 5.32 Ge [Ar]$3d^{10} 4s^2 p^2$ Germanium	33 74.9216 ±3,5 876 (subl.) 1090 (39 atm.) 5.78 As [Ar]$3d^{10} 4s^2 p^3$ Arsenic	34 78.96 -2,4,6 958 494 4.79 Se [Ar]$3d^{10} 4s^2 p^4$ Selenium	35 79.904 ±1,5,7 331.85 265.95 3.12 Br [Ar]$3d^{10} 4s^2 p^5$ Bromine	36 8 120.85 116 3.75† K [Ar]$3d^{10} 4s$ Krypto
7 85.4678 1 63 32 Rb [Kr]$5s^1$ ubidium	38 87.62 2 1655 1042 2.54 Sr [Kr]$5s^2$ Strontium	39 88.9059 3 3611 1795 4.47 Y [Kr]$4d^1 5s^2$ Yttrium	40 91.224 4 4682 2128 6.51 Zr [Kr]$4d^2 5s^2$ Zirconium	41 92.9064 5,3 5015 2742 8.57 Nb [Kr]$4d^4 5s^1$ Niobium	42 95.94 6,5,4,3,2 4912 2896 10.22 Mo [Kr]$4d^5 5s^1$ Molybdenum	43 (98) 7 4538 2477 11.5 Tc [Kr]$4d^5 5s^2$ Technetium	44 101.07 2,3,4,6,8 4425 2610 12.37 Ru [Kr]$4d^7 5s^1$ Ruthenium	45 102.9055 2,3,4 3970 2236 12.41 Rh [Kr]$4d^8 5s^1$ Rhodium	46 106.42 2,4 3240 1825 12.0 Pd [Kr]$4d^{10}$ Palladium	47 107.868 1 2436 1235.08 10.50 Ag [Kr]$4d^{10} 5s^1$ Silver	48 112.41 2 1040 594.26 8.65 Cd [Kr]$4d^{10} 5s^2$ Cadmium	49 114.82 3 2350 429.78 7.31 In [Kr]$4d^{10} 5s^2 p^1$ Indium	50 118.710 4,2 2876 505.12 7.31 Sn [Kr]$4d^{10} 5s^2 p^2$ Tin	51 121.760 ±3,5 1860 903.91 6.69 Sb [Kr]$4d^{10} 5s^2 p^3$ Antimony	52 127.60 -2,4,6 1261 722.72 6.24 Te [Kr]$4d^{10} 5s^2 p^4$ Tellurium	53 126.9045 ±1,5,7 457.5 386.7 4.93 I [Kr]$4d^{10} 5s^2 p^5$ Iodine	54 13 0 165.1 161.39 5.90† X [Kr]$4d^{10} 5s$ Xenon
5 132.9054 1 54 Cs [Xe]$6s^1$ Cesium	56 137.33 2 2078 1002 3.59 Ba [Xe]$6s^2$ Barium	57 138.9055 3 ★ 3737 1191 6.15 La [Xe]$5d^1 6s^2$ Lanthanum	72 178.49 4 4875 2504 13.31 Hf [Xe]$4f^{14} 5d^2 6s^2$ Hafnium	73 180.9479 5 5730 3293 16.65 Ta [Xe]$4f^{14} 5d^3 6s^2$ Tantalum	74 183.84 6,5,4,3,2 5825 3695 19.3 W [Xe]$4f^{14} 5d^4 6s^2$ Tungsten	75 186.207 7,6,4,2 5870 3455 21.0 Re [Xe]$4f^{14} 5d^5 6s^2$ Rhenium	76 190.23 2,3,4,6,8 5300 3300 22.6 Os [Xe]$4f^{14} 5d^6 6s^2$ Osmium	77 192.22 2,3,4,6 4700 2720 22.6 Ir [Xe]$4f^{14} 5d^7 6s^2$ Iridium	78 195.08 2,4 4100 2042.1 21.45 Pt [Xe]$4f^{14} 5d^9 6s^1$ Platinum	79 196.9665 3,1 3130 1337.58 19.3 Au [Xe]$4f^{14} 5d^{10} 6s^1$ Gold	80 200.59 2,1 629.88 234.31 13.55 Hg [Xe]$4f^{14} 5d^{10} 6s^2$ Mercury	81 204.383 3,1 1746 577 11.85 Tl [Xe]$4f^{14} 5d^{10} 6s^2 p^1$ Thallium	82 207.2 4,2 2023 600.65 11.35 Pb [Xe]$4f^{14} 5d^{10} 6s^2 p^2$ Lead	83 208.9804 3,5 1837 544.59 9.75 Bi [Xe]$4f^{14} 5d^{10} 6s^2 p^3$ Bismuth	84 (209) 4,2,6 — 527 9.3 Po [Xe]$4f^{14} 5d^{10} 6s^2 p^4$ Polonium	85 (210) ±1,3,5,7 610* 575 — At [Xe]$4f^{14} 5d^{10} 6s^2 p^5$ Astatine	86 211.4 202 9.73 R [Xe]$4f^{14} 5d^{10}$ Radon
7 (223) 1 Fr [Rn]$7s^1$ rancium	88 (226) 2 1413 973 5.0 Ra [Rn]$7s^2$ Radium	89 (227) 3 ★★ 3470* 1324 10.07 Ac [Rn]$6d^1 7s^2$ Actinium	104 (261) — — — Rf [Rn]$5f^{14} 6d^2 7s^2$* Rutherfordium	105 (262) — — — Db [Rn]$5f^{14} 6d^3 7s^2$* Dubnium	106 (263) — — — Sg [Rn]$5f^{14} 6d^4 7s^2$* Seaborgium	107 (264) — — — Bh [Rn]$5f^{14} 6d^5 7s^2$* Bohrium	108 (265) — — — Hs [Rn]$5f^{14} 6d^6 7s^2$* Hassium	109 (268) — — — Mt [Rn]$5f^{14} 6d^7 7s^2$* Meitnerium	110 (269) — — — Uun [Rn]$5f^{14} 6d^8 7s^2$* (Ununnilium)	111 (272) — — — Uuu [Rn]$5f^{14} 6d^9 7s^2$* (Unununium)	112 (277) — — — Uub [Rn]$5f^{14} 6d^{10} 7s^2$* (Ununbium)	113 Uut (Ununtrium)	114 (285) — — — Uuq [Rn]$5f^{14} 6d^{10} 7s^2 7p^2$* (Ununquadium)	115 Uup (Ununpentium)	116 Uuh (Ununhexium)	117 Uus (Ununseptium)	118 U (Ununocti

timated Values



★	58 140.12 3,4 3715 1071 6.77 Ce [Xe]$4f^1 5d^1 6s^2$ Cerium	59 140.9077 3,4 3785 1204 6.77 Pr [Xe]$4f^3 6s^2$ Praseodymium	60 144.24 3 3347 1294 7.01 Nd [Xe]$4f^4 6s^2$ Neodymium	61 (145) 3 3273 1315 7.22 Pm [Xe]$4f^5 6s^2$ Promethium	62 150.36 3,2 2067 1347 7.52 Sm [Xe]$4f^6 6s^2$ Samarium	63 151.964 3,2 1800 1095 5.24 Eu [Xe]$4f^7 6s^2$ Europium	64 157.25 3 3545 1585 7.90 Gd [Xe]$4f^7 5d^1 6s^2$ Gadolinium	65 158.9253 3,4 3500 1629 8.23 Tb [Xe]$4f^9 6s^2$ Terbium	66 162.50 3 2840 1685 8.55 Dy [Xe]$4f^{10} 6s^2$ Dysprosium	67 164.9303 3 2968 1747 8.80 Ho [Xe]$4f^{11} 6s^2$ Holmium	68 167.26 3 3140 1802 9.07 Er [Xe]$4f^{12} 6s^2$ Erbium	69 168.9342 3,2 2223 1818 9.32 Tm [Xe]$4f^{13} 6s^2$ Thulium	70 173.04 3,2 1469 1092 6.97 Yb [Xe]$4f^{14} 6s^2$ Ytterbium	71 174.967 3 3668 1936 9.84 Lu [Xe]$4f^{14} 5d^1 6s^2$ Lutetium
★★	90 232.0381 4 5060 2028 11.72 Th [Rn]$6d^2 7s^2$ Thorium	91 231.0359 5,4 4300* 1845 15.4 Pa [Rn]$5f^2 6d^1 7s^2$ Protactinium	92 238.029 6,5,4,3 4407 1408 18.95 U [Rn]$5f^3 6d^1 7s^2$ Uranium	93 (237) 6,5,4,3 4175* 912 20.2 Np [Rn]$5f^4 6d^1 7s^2$ Neptunium	94 (244) 6,5,4,3 3505 913 19.84 Pu [Rn]$5f^6 7s^2$ Plutonium	95 (243) 6,5,4,3 2880 1449 13.7 Am [Rn]$5f^7 7s^2$ Americium	96 (247) 3 — 1620 13.5 Cm [Rn]$5f^7 6d^1 7s^2$ Curium	97 (247) 4,3 — — 14* Bk [Rn]$5f^9 7s^2$ Berkelium	98 (251) 3 — 1170* — Cf [Rn]$5f^{10} 7s^2$ Californium	99 (252) 3 — 1130* — Es [Rn]$5f^{11} 7s^2$ Einsteinium	100 (257) 3 — 1800* — Fm [Rn]$5f^{12} 7s^2$ Fermium	101 (258) 3 — 1100* — Md [Rn]$5f^{13} 7s^2$ Mendelevium	102 (259) 2,3 — 1100* — No [Rn]$5f^{14} 7s^2$ Nobelium	103 (262) 3 — 1900* — Lr [Rn]$5f^{14} 6d^1 7s^2$ Lawrencium

NOTES:

(1) Black — solid

(2) Based upon carbon-12. ( ) indicates most

The A & B subgroup designations, are those recommended by the Inter

Moles, cont

- The number of moles can be determined from the mass of the substance: $\boldsymbol{n = m / M}$
  - – M is the molar mass of the substance
  - – m is the mass of the sample
  - – n is the number of moles

How much one mole of Al_2S_3 (Aluminum Sulfide) weighs?

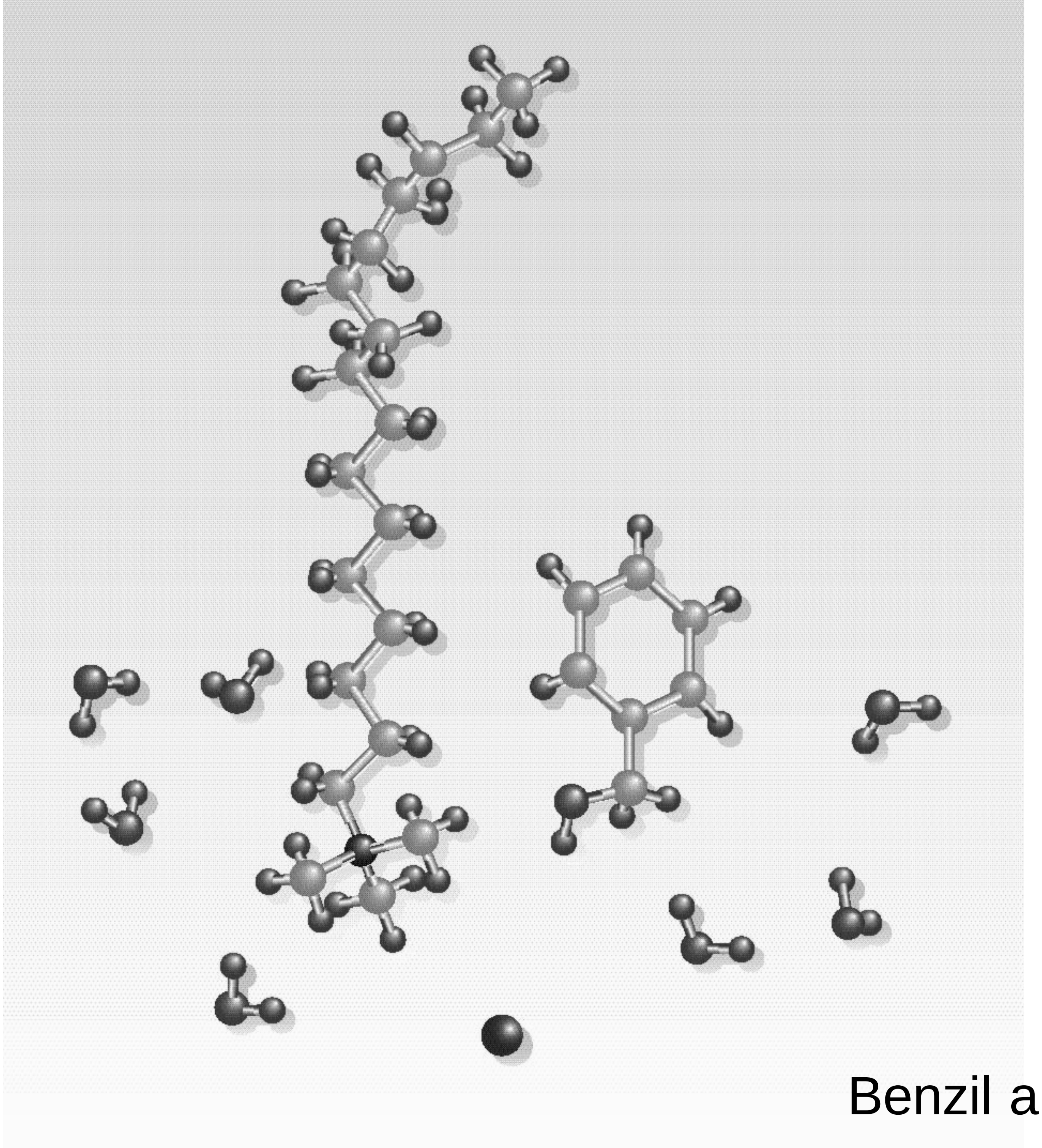
A basic assumption is that in one mole of Al_2S_3, there are two moles of Al and three moles of S.

Using this assumption, there are 2 moles of Al and 3 moles of S

So take 26.98 grams (which is the weight of 1 mole of Al) and multiply it by 2.

Then take 32.06 grams (which is the weight of 1 mole of S) and multiply it by 3

Then add the two amounts up.
2 mol Al = 2 (26.98) = 53.96 g
3 mol S = 3 (32.06) = 96.18 g
Total - 150.14 g



Benzil alcohol molecule

Equations of State

- P,V,T, and n are not independent.
- Any three will determine the fourth.
- An equation of state is an equation that relates P,V,T, and n for a given substance.
- Gases have the simplest equations of state.

Ideal Gas Law

First written in 1834 by Emil Clapeyron

- The equation of state for an ideal gas combines and summarizes the other gas laws

$$PV = n \times R \times T$$

$$\text{where } n \times R = N \times k = n \times N_A \times k$$

- *R* is a constant, called the Universal Gas Constant

$$R = 8.314 \text{ J/mol} \cdot \text{K}$$

Ideal Gas Law, cont

- The ideal gas law is often expressed in terms of the total number of molecules, N, present in the sample
- $PV = nRT = (N/N_A)\ RT = Nk_\mathrm{B}T$
  - k_B is Boltzmann's constant
  - **$\boldsymbol{k_\mathrm{B} = 1.38 \times 10^{-23}}$ J/K**
- It is common to call P, V, and T the **thermodynamic variables** of an ideal gas

Composition

- moles: n_i

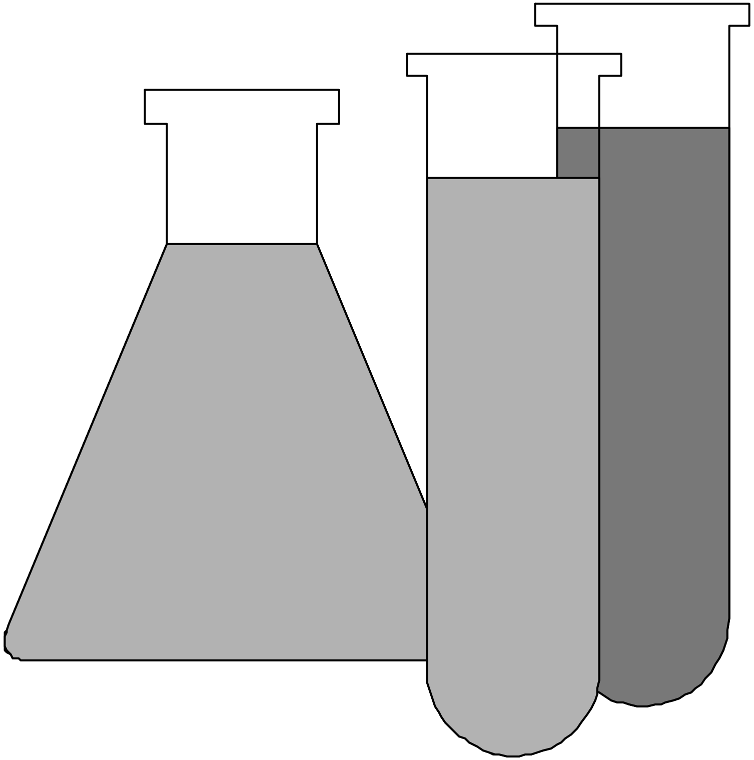
  $\Sigma n_i = n$

- mole fraction: x_i

  $\Sigma x_i = 1$

- partial pressure: p_i

  $\Sigma p_i = p$



Dalton’s Law of partial pressures

$\mathbf{N = N_1 + N_2 + N_3 \ldots + \ldots}$

Because $\mathbf{N = PV/\, k_B T}$ **and** $\mathbf{N_i = P_i V/\, k_B T}$**,** $\mathbf{i = 1,2,3,\ldots}$

$\mathbf{PV/\, k_B T = P_1 V/\, k_B T + P_2 V/\, k_B T + P_3 V/\, k_B T + \ldots}$

Or

$\mathbf{P = P_1 + P_2 + P_3 + \ldots}$ **- Dalton’s law**

Ideal Gas Law in Action

A balloonist fills his balloon with $n = 10{,}000$ moles of H_2. On the ground, where

$P = 1\ \text{atm} = 1.013 \times 10^5\ \text{Pa}$

$T = 293\ \text{K} = 20°\text{C}$

what is the volume of the balloon?

$$V = \frac{nRT}{P} = \frac{(10^4\ \text{moles})(8.31\ \frac{\text{J}}{\text{mol}\cdot\text{K}})(293\text{k}}{1.013 \times 10^5\ \text{Pa}}$$

$= 240\ \text{m}^3$ **r = 3.9 m**

The balloon rises to an altitude at which pressure is 1/10 atmosphere:

$P = 0.1\ \text{atm} = 1.013 \times 10^4\ \text{Pa}$

Balloon expands

$$V = \frac{(10^4\ \text{moles})(8.31\ \frac{\text{J}}{\text{mol}\cdot\text{K}})(293\ \text{K})}{1.013 \times 10^4\ \text{Pa}}$$

$= 2400\ \text{m}^3$ **r = 8.3 m**

At night, the air temperature drops from 20 °C → -10 °C. Thats

$$T = 293\,K \rightarrow 263\,K$$

How much does the balloon shrink?

$$V = \frac{nRT}{P}$$

$$= \frac{(10^4\ mol)\left(8.31\ \frac{J}{mol\cdot K}\right)(263\,K)}{1.013 \times 10^4\ Pa}$$

$$= 2160\ m^3$$

$r = 8.0\ m$

Don't forget: a sphere has volume

$$V = \frac{4}{3}\pi r^3$$