

## CHAPTER 1

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# Atomic and Molecular Mass

A proton and a neutron have about the same mass. An electron, on the other hand, has much less mass: One neutron weighs about the same amount as 2000 electrons. Thus, the mass of any object comes mostly from the protons and neutrons in the nucleus of its atoms.

We know how many protons an atom has by what element it is, but how do we know the number neutrons?

If you fill a balloon with helium, it will have two different kinds of helium atoms: Most of the helium atoms will have 2 neutrons, but a few will have only 1 neutron. We say that these are two different *isotopes* of helium. We call them helium-4 (or  ${}^4\text{He}$ ) and helium-3 (or  ${}^3\text{He}$ ). Isotopes are named for the sum of protons and neutrons the atom has: helium-3 has 2 protons and 1 neutron.

Watch Khan Academy's **Atomic mass, number, and isotopes** at <https://www.khanacademy.org/science/chemistry/atomic-structure-and-properties/introduction-to-the-atom/v/atomic-number-mass-number-and-isotopes>

A hydrogen atom nearly always has just 1 proton and no neutrons. A helium atom nearly always has 2 protons and 2 neutrons. So, if you have a 100 hydrogen atoms and 100 helium atoms, the helium will have about 4 times more mass than the hydrogen. We say "Hydrogen is about 1 atomic mass unit(amu), and helium-4 is about 4 atomic mass units."

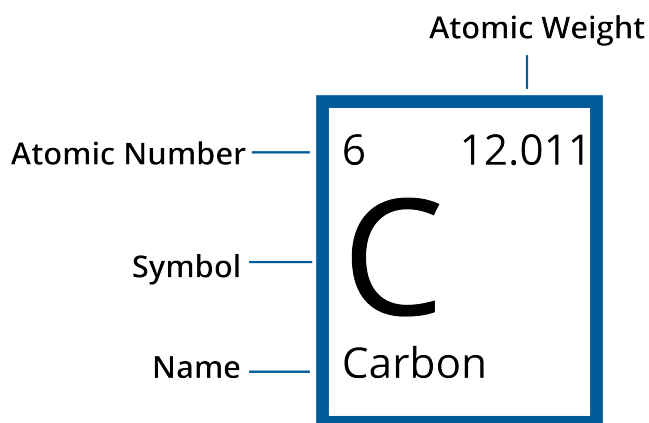
What, precisely, is an atomic mass unit? It is defined as 1/12 of the mass of a carbon-12 atom. Scientists have measured the mass of helium-4, and it is about 4.0026 atomic mass units. (By the way, an atomic mass unit is also called a *dalton*.)

Now you are ready to take a good look at the periodic table of elements. Here is the version from Wikipedia:

IA		Periodic Table of Elements																VIIA																																																																																																																																																																																																																																																																																																																																													
1 <b>H</b> Hydrogen 1.01	IIA																		2 <b>He</b> Helium 4.00																																																																																																																																																																																																																																																																																																																																												
3 <b>Li</b> Lithium 6.94	4 <b>Be</b> Beryllium 9.01																	10 <b>Ne</b> Neon 20.18																																																																																																																																																																																																																																																																																																																																													
11 <b>Na</b> Sodium 22.99	12 <b>Mg</b> Magnesium 24.31	III B	IV B	VB	VIB	VII B	VIII B	VIII B	VIII B	IB	II B	III A	IVA	VA	VIA	VIIA																																																																																																																																																																																																																																																																																																																																															
19 <b>K</b> Potassium 39.10	20 <b>Ca</b> Calcium 40.08	21 <b>Sc</b> Scandium 44.96	22 <b>Ti</b> Titanium 47.87	23 <b>V</b> Vanadium 50.94	24 <b>Cr</b> Chromium 52.00	25 <b>Mn</b> Manganese 54.94	26 <b>Fe</b> Iron 55.85	27 <b>Co</b> Cobalt 58.93	28 <b>Ni</b> Nickel 58.69	29 <b>Cu</b> Copper 63.55	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.72	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.92	34 <b>Se</b> Selenium 78.97	35 <b>Br</b> Bromine 79.90	36 <b>Kr</b> Krypton 83.80																																																																																																																																																																																																																																																																																																																																														
37 <b>Rb</b> Rubidium 85.47	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.91	40 <b>Zr</b> Zirconium 91.22	41 <b>Nb</b> Niobium 92.91	42 <b>Mo</b> Molybdenum 95.95	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.91	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.87	48 <b>Cd</b> Cadmium 112.41	49 <b>In</b> Indium 114.82	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.60	53 <b>I</b> Iodine 126.90	54 <b>Xe</b> Xenon 131.29																																																																																																																																																																																																																																																																																																																																														
55 <b>Cs</b> Cesium 132.91	56 <b>Ba</b> Barium 137.33	Lanthanides																86 <b>Rn</b> Radon (222)																																																																																																																																																																																																																																																																																																																																													
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	Actinides																118 <b>Og</b> Oganesson (294)																																																																																																																																																																																																																																																																																																																																													
																		104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (270)	108 <b>Hs</b> Hassium (277)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Nh</b> Nihonium (294)	114 <b>Fl</b> Flerovium 289	115 <b>Mc</b> Moscovium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Ts</b> Tennessine (294)																																																																																																																																																																																																																																																																																																																																
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<b>Uuq</b> Ununquadium (258)	152 <b>Uuh</b> Ununhexium (257)	153 <b>Uus</b> Ununseptium (256)	154 <b>Uuo</b> Ununoctium (255)	155 <b>Uut</b> Unutrium (254)	156 <b>Uub</b> Unubium (253)	157 <b>Uut</b> Ununtrium (252)	158 <b>Uuq</b> Ununquadium (251)	159 <b>Uuh</b> Ununhexium (250)	160 <b>Uus</b> Ununseptium (249)	161 <b>Uuo</b> Ununoctium (248)	162 <b>Uut</b> Unutrium (247)	163 <b>Uub</b> Unubium (246)	164 <b>Uut</b> Ununtrium (245)	165 <b>Uuq</b> Ununquadium (244)	166 <b>Uuh</b> Ununhexium (243)	167 <b>Uus</b> Ununseptium (242)	168 <b>Uuo</b> Ununoctium (241)	169 <b>Uut</b> Unutrium (240)	170 <b>Uub</b> Unubium (239)	171 <b>Uut</b> Ununtrium (238)	172 <b>Uuq</b> Ununquadium (237)	173 <b>Uuh</b> Ununhexium (236)	174 <b>Uus</b> Ununseptium (235)	175 <b>Uuo</b> Ununoctium (234)	176 <b>Uut</b> Unutrium (233)	177 <b>Uub</b> Unubium (232)	178 <b>Uut</b> Ununtrium (231)	179 <b>Uuq</b> Ununquadium (230)	180 <b>Uuh</b> Ununhexium (229)	181 <b>Uus</b> Ununseptium (228)	182 <b>Uuo</b> Ununoctium (227)	183 <b>Uut</b> Unutrium (226)	184 <b>Uub</b> Unubium (225)	185 <b>Uut</b> Ununtrium (224)	186 <b>Uuq</b> Ununquadium (223)	187 <b>Uuh</b> Ununhexium (222)	188 <b>Uus</b> Ununseptium (221)	189 <b>Uuo</b> Ununoctium (220)	190 <b>Uut</b> Unutrium (219)	191 <b>Uub</b> Unubium (218)	192 <b>Uut</b> Ununtrium (217)	193 <b>Uuq</b> Ununquadium (216)	194 <b>Uuh</b> Ununhexium (215)	195 <b>Uus</b> Ununseptium (214)	196 <b>Uuo</b> Ununoctium (213)	197 <b>Uut</b> Unutrium (212)	198 <b>Uub</b> Unubium (211)	199 <b>Uut</b> Ununtrium (210)	200 <b>Uuq</b> Ununquadium (209)	201 <b>Uuh</b> Ununhexium (208)	202 <b>Uus</b> Ununseptium (207)	203 <b>Uuo</b> Ununoctium (206)	204 <b>Uut</b> Unutrium (205)	205 <b>Uub</b> Unubium (204)	206 <b>Uut</b> Ununtrium (203)	207 <b>Uuq</b> Ununquadium (202)	208 <b>Uuh</b> Ununhexium (201)	209 <b>Uus</b> Ununseptium (200)	210 <b>Uuo</b> Ununoctium (199)	211 <b>Uut</b> Unutrium (198)	212 <b>Uub</b> Unubium (197)	213 <b>Uut</b> Ununtrium (196)	214 <b>Uuq</b> Ununquadium (195)	215 <b>Uuh</b> Ununhexium (194)	216 <b>Uus</b> Ununseptium (193)	217 <b>Uuo</b> Ununoctium (192)	218 <b>Uut</b> Unutrium (191)	219 <b>Uub</b> Unubium (190)	220 <b>Uut</b> Ununtrium (189)	221 <b>Uuq</b> Ununquadium (188)	222 <b>Uuh</b> Ununhexium (187)	223 <b>Uus</b> Ununseptium (186)	224 <b>Uuo</b> Ununoctium (185)	225 <b>Uut</b> Unutrium (184)	226 <b>Uub</b> Unubium (183)	227 <b>Uut</b> Ununtrium (182)	228 <b>Uuq</b> Ununquadium (181)	229 <b>Uuh</b> Ununhexium (180)	230 <b>Uus</b> Ununseptium (179)	231 <b>Uuo</b> Ununoctium (178)	232 <b>Uut</b> Unutrium (177)	233 <b>Uub</b> Unubium (176)	234 <b>Uut</b> Ununtrium (175)	235 <b>Uuq</b> Ununquadium (174)	236 <b>Uuh</b> Ununhexium (173)	237 <b>Uus</b> Ununseptium (172)	238 <b>Uuo</b> Ununoctium (171)	239 <b>Uut</b> Unutrium (170)	240 <b>Uub</b> Unubium (169)	241 <b>Uut</b> Ununtrium (168)	242 <b>Uuq</b> Ununquadium (167)	243 <b>Uuh</b> Ununhexium (166)	244 <b>Uus</b> Ununseptium (165)	245 <b>Uuo</b> Ununoctium (164)	246 <b>Uut</b> Unutrium (163)	247 <b>Uub</b> Unubium (162)	248 <b>Uut</b> Ununtrium (161)	249 <b>Uuq</b> Ununquadium (160)	250 <b>Uuh</b> Ununhexium (159)	251 <b>Uus</b> Ununseptium (158)	252 <b>Uuo</b> Ununoctium (157)	253 <b>Uut</b> Unutrium (156)	254 <b>Uub</b> Unubium (155)	255 <b>Uut</b> Ununtrium (154)	256 <b>Uuq</b> Ununquadium (153)	257 <b>Uuh</b> Ununhexium (152)	258 <b>Uus</b> Ununseptium (151)	259 <b>Uuo</b> Ununoctium (150)	260 <b>Uut</b> Unutrium (149)	261 <b>Uub</b> Unubium (148)	262 <b>Uut</b> Ununtrium (147)	263 <b>Uuq</b> Ununquadium (146)	264 <b>Uuh</b> Ununhexium (145)	265 <b>Uus</b> Ununseptium (144)	266 <b>Uuo</b> Ununoctium (143)	267 <b>Uut</b> Unutrium (142)	268 <b>Uub</b> Unubium (141)	269 <b>Uut</b> Ununtrium (140)	270 <b>Uuq</b> Ununquadium (139)	271 <b>Uuh</b> Ununhexium (138)	272 <b>Uus</b> Ununseptium (137)	273 <b>Uuo</b> Ununoctium (136)	274 <b>Uut</b> Unutrium (135)	275 <b>Uub</b> Unubium (134)	276 <b>Uut</b> Ununtrium (133)	277 <b>Uuq</b> Ununquadium (132)	278 <b>Uuh</b> Ununhexium (131)	279 <b>Uus</b> Ununseptium (130)	280 <b>Uuo</b> Ununoctium (129)	281 <b>Uut</b> Unutrium (128)	282 <b>Uub</b> Unubium (127)	283 <b>Uut</b> Ununtrium (126)	284 <b>Uuq</b> Ununquadium (125)	285 <b>Uuh</b> Ununhexium (124)	286 <b>Uus</b> Ununseptium (123)	287 <b>Uuo</b> Ununoctium (122)	288 <b>Uut</b> Unutrium (121)	289 <b>Uub</b> Unubium (120)	290 <b>Uut</b> Ununtrium (119)	291 <b>Uuq</b> Ununquadium (118)	292 <b>Uuh</b> Ununhexium (117)	293 <b>Uus</b> Ununseptium (116)	294 <b>Uuo</b> Ununoctium (115)	295 <b>Uut</b> Unutrium (114)	296 <b>Uub</b> Unubium (113)	297 <b>Uut</b> Ununtrium (112)	298 <b>Uuq</b> Ununquadium (111)	299 <b>Uuh</b> Ununhexium (110)	300 <b>Uus</b> Ununseptium (109)	301 <b>Uuo</b> Ununoctium (108)	302 <b>Uut</b> Unutrium (107)	303 <b>Uub</b> Unubium (106)	304 <b>Uut</b> Ununtrium (105)	305 <b>Uuq</b> Ununquadium (104)	306 <b>Uuh</b> Ununhexium (103)	307 <b>Uus</b> Ununseptium (102)	308 <b>Uuo</b> Ununoctium (101)	309 <b>Uut</b> Unutrium (100)	310 <b>Uub</b> Unubium (99)	311 <b>Uut</b> Ununtrium (98)	312 <b>Uuq</b> Ununquadium (97)	313 <b>Uuh</b> Ununhexium (96)	314 <b>Uus</b> Ununseptium (95)	315 <b>Uuo</b> Ununoctium (94)	316 <b>Uut</b> Unutrium (93)	317 <b>Uub</b> Unubium (92)	318 <b>Uut</b> Ununtrium (91)	319 <b>Uuq</b> Ununquadium (90)	320 <b>Uuh</b> Ununhexium (89)	321 <b>Uus</b> Ununseptium (88)	322 <b>Uuo</b> Ununoctium (87)	323 <b>Uut</b> Unutrium (86)	324 <b>Uub</b> Unubium (85)	325 <b>Uut</b> Ununtrium (84)	326 <b>Uuq</b> Ununquadium (83)	327 <b>Uuh</b> Ununhexium (82)	328 <b>Uus</b> Ununseptium (81)	329 <b>Uuo</b> Ununoctium (80)	330 <b>Uut</b> Unutrium (79)	331 <b>Uub</b> Unubium (78)	332 <b>Uut</b> Ununtrium (77)	333 <b>Uuq</b> Ununquadium (76)	334 <b>Uuh</b> Ununhexium (75)	335 <b>Uus</b> Ununseptium (74)	336 <b>Uuo</b> Ununoctium (73)	337 <b>Uut</b> Unutrium (72)	338 <b>Uub</b> Unubium (71)	339 <b>Uut</b> Ununtrium (70)	340 <b>Uuq</b> Ununquadium (69)	341 <b>Uuh</b> Ununhexium (68)	342 <b>Uus</b> Ununseptium (67)	343 <b>Uuo</b> Ununoctium (66)	344 <b>Uut</b> Unutrium (65)	345 <b>Uub</b> Unubium (64)	346 <b>Uut</b> Ununtrium (63)	347 <b>Uuq</b> Ununquadium (62)	348 <b>Uuh</b> Ununhexium (61)	349 <b>Uus</b> Ununseptium (60)	350 <b>Uuo</b> Ununoctium (59)	351 <b>Uut</b> Unutrium (58)	352 <b>Uub</b> Unubium (57)	353 <b>Uut</b> Ununtrium (56)	354 <b>Uuq</b> Ununquadium (55)	355 <b>Uuh</b> Ununhexium (54)	356 <b>Uus</b> Ununseptium (53)	357 <b>Uuo</b> Ununoctium (52)	358 <b>Uut</b> Unutrium (51)	359 <b>Uub</b> Unubium (50)	360 <b>Uut</b> Ununtrium (49)	361 <b>Uuq</b> Ununquadium (48)	362 <b>Uuh</b> Ununhexium (47)	363 <b>Uus</b> Ununseptium (46)	364 <b>Uuo</b> Ununoctium (45)	365 <b>Uut</b> Unutrium (44)	366 <b>Uub</b> Unubium (43)	367 <b>Uut</b> Ununtrium (42)	368 <b>Uuq</b> Ununquadium (41)	369 <b>Uuh</b> Ununhexium (40)	370 <b>Uus</b> Ununseptium (39)	371 <b>Uuo</b> Ununoctium (38)	372 <b>Uut</b> Unutrium (37)	373 <b>Uub</b> Unubium (36)	374 <b>Uut</b> Ununtrium (35)	375 <b>Uuq</b> Ununquadium (34)	376 <b>Uuh</b> Ununhexium (33)	377 <b>Uus</b> Ununseptium (32)	378 <b>Uuo</b> Ununoctium (31)	379 <b>Uut</b> Unutrium (30)	380 <b>Uub</b> Unubium (29)	381 <b>Uut</b> Ununtrium (28)	382 <b>Uuq</b> Ununquadium (27)	383 <b>Uuh</b> Ununhexium (26)	384 <b>Uus</b> Ununseptium (25)	385 <b>Uuo</b> Ununoctium (24)	386 <b>Uut</b> Unutrium (23)	387 <b>Uub</b> Unubium (22)	388 <b>Uut</b> Ununtrium (21)	389 <b>Uuq</b> Ununquadium (20)	390 <b>Uuh</b> Ununhexium (19)	391 <b>Uus</b> Ununseptium (18)	392 <b>Uuo</b> Ununoctium (17)	393 <b>Uut</b> Unutrium (16)	394 <b>Uub</b> Unubium (15)	395 <b>Uut</b> Ununtrium (14)	396 <b>Uuq</b> Ununquadium (13)	397 <b>Uuh</b> Ununhexium (12)	398 <b>Uus</b> Ununseptium (11)	399 <b>Uuo</b> Ununoctium (10)	400 <b>Uut</b> Unutrium (9)	401 <b>Uub</b> Unubium (8)	402 <b>Uut</b> Ununtrium (7)	403 <b>Uuq</b> Ununquadium (6)	404 <b>Uuh</b> Ununhexium (5)	405 <b>Uus</b> Ununseptium (4)	406 <b>Uuo</b> Ununoctium (3)	407 <b>Uut</b> Unutrium (2)	408 <b>Uub</b> Unubium (1)	409 <b>Uut</b> Ununtrium (0)	410 <b>Uuq</b> Ununquadium (-1)	411 <b>Uuh</b> Ununhexium (-2)	412 <b>Uus</b> Ununseptium (-3)	413 <b>Uuo</b> Ununoctium (-4)	414 <b>Uut</b> Unutrium (-5)	415 <b>Uub</b> Unubium (-6)	416 <b>Uut</b> Ununtrium (-7)	417 <b>Uuq</b> Ununquadium (-8)	418 <b>Uuh</b> Ununhexium (-9)	419 <b>Uus</b> Ununseptium (-10)	420 <b>Uuo</b> Ununoctium (-11)	421 <b>Uut</b> Unutrium (-12)	422 <b>Uub</b> Unubium (-13)	423 <b>Uut</b> Ununtrium (-14)	424 <b>Uuq</b> Ununquadium (-15)	425 <b>Uuh</b> Ununhexium (-16)	426 <b>Uus</b> Ununseptium (-17)	427 <b>Uuo</b> Ununoctium (-18)	428 <b>Uut</b> Unutrium (-19)	429 <b>Uub</b> Unubium (-20)	430 <b>Uut</b> Ununtrium (-21)	431 <b>Uuq</b> Ununquadium (-22)	432 <b>Uuh</b> Ununhexium (-23)	433 <b>Uus</b> Ununseptium (-24)	434 <b>Uuo</b> Ununoctium (-25)	435 <b>Uut</b> Unutrium (-26)	436 <b>Uub</b> Unubium (-27)	437 <b>Uut</b> Ununtrium (-28)	438 <b>Uuq</b> Ununquadium (-29)	439 <b>Uuh</b> Ununhexium (-30)	440 <b>Uus</b> Ununseptium (-31)	441 <b>Uuo</b> Ununoctium (-32)	442 <b>Uut</b> Unutrium (-33)	443 <b>Uub</b> Unubium (-34)	444 <b>Uut</b> Ununtrium (-35)	445 <b>Uuq</b> Ununquadium (-36)	446 <b>Uuh</b> Ununhexium (-37)	447 <b>Uus</b> Ununseptium (-38)	448 <b>Uuo</b> Ununoctium (-39)	449 <b>Uut</b> Unutrium (-40)	450 <b>Uub</b> Unubium (-41)	451 <b>Uut</b> Ununtrium (-42)	452 <b>Uuq</b> Ununquadium (-43)	4

There is a square for each element. In the middle, you see the atomic symbol and the name of the element. In the upper right corner is the atomic number – the number of protons in the atom.

In the upper left corner is the atomic mass in atomic mass units.



Look at the atomic mass of boron. About 80% of all boron atoms have six neutrons. The other 20% have only 5 neutrons. So most boron atoms have a mass of about 11 atomic mass units, but some have a mass of about 10 atomic mass units. The atomic mass of boron is equivalent to the average mass of a boron atom: 10.811.

### Exercise 1      Mass of a Water Molecule

Working Space

Using the periodic table, what is the average mass of one water molecule in atomic mass units?

Answer on Page 7

## 1.1 Molar Mass

An atomic mass unit is a very, very, very small unit; we would much rather work in grams. It turns out that  $6.02214076 \times 10^{23}$  atoms equal 1 mole (a standard measure for chemistry). Scientists use this number so much that they gave it a name: *the Avogadro constant* or *Avogadro's number*.

Watch Khan Academy's discussion of the mole at <https://www.khanacademy.org/science/ap-chemistry-beta/x2eef969c74e0d802:atomic-structure-and-properties/x2eef969c74e0d802:moles-and-molar-mass/v/the-mole-and-avogadro-s-number>

If you have 12 doughnuts, that's a dozen doughnuts. If you have  $6.02214076 \times 10^{23}$  doughnuts, you have a *mole* of doughnuts. (Note: it isn't practical to measure doughnuts this way: A mole of doughnuts would be about the size of the earth. We use moles for small things like molecules.)

Let's say you want to know how much a mole of NaCl weighs. From the periodic table, you see that Na has an atomic mass of 22.98976 atomic mass units. And Cl has 35.453 atomic mass units. One atom of NaCl has a mass of  $22.98976 + 35.453 = 58.44276$  atomic mass units. Then a mole of NaCl has a mass of 58.44276 grams. Handy, right?

### Exercise 2 Burning Methane

Working Space

Natural gas is mostly methane ( $\text{CH}_4$ ). When one molecule of methane burns, two oxygen molecules ( $\text{O}_2$ ) are consumed. One molecule of  $\text{H}_2\text{O}$  and one molecule of  $\text{CO}_2$  are produced.

If I need 200 grams of water, how many grams of methane do I need to burn?

(This is how the hero in "The Martian" made water for his garden.

Answer on Page 7

## 1.2 Heavy atoms aren't stable

When you look at the periodic table, there are a surprisingly large number of elements. You might be told to “Drink milk so that you can get the calcium you need.” However, no one has told you “You should eat kale so that you get enough copernicium in your diet.”

Copernicium, with 112 protons and 173 neutrons, has only been observed in a lab. It is highly radioactive and unstable (meaning it decays): a copernicium atom usually lives for less than a minute before decaying.

The largest stable element is lead, which has 82 protons and between 122 and 126 neutrons. Elements with lower atomic numbers than lead, have at least one stable isotope. Elements with higher atomic numbers than lead don't.

Bismuth, with an atomic number of 83, is *almost* stable. In fact, most bismuth atoms will live for billions of years before decaying.

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*This is a draft chapter from the Kontinua Project. Please see our website (<https://kontinua.org/>) for more details.*



# Answers to Exercises

### Answer to Exercise 1 (on page 3)

The average hydrogen atom has a mass of 1.00794 atomic mass units.

The average oxygen atom has a mass of 15.9994.

$$2 \times 1.00794 + 15.9994 = 18.01528 \text{ atomic mass units.}$$

### Answer to Exercise 2 (on page 4)

From the last exercise, you know that 1 mole of water weighs 18.01528 grams. So 200 grams of water is about 11.1 moles. So you need to burn 11.1 moles of methane.

What does one mole of methane weigh? Using the periodic table:  $12.0107 + 4 \times 1.00794 = 16.04246$  grams.

$$16.0424 \times 11.10 = 178.1 \text{ grams of methane.}$$







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# INDEX

atomic mass, [3](#)

atomic mass unit, [1](#)

Avogadro's number, [4](#)

isotopes, [1](#)

mole, [4](#)

neutron, [1](#)

periodic table of elements, [2](#)

proton, [1](#)