Making Phosphoric Acid

- Furnace Process for making H_3PO_4 to be used to make fertilizers, detergents, and pharmaceuticals.
  - React phosphate rock with sand and coke at 2000 ºC.

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \rightarrow 4P + 10CO + 6CaSiO_3$$

  - React phosphorus with oxygen to get tetraphosphorus decoxide.

$$4P + 5O_2 \rightarrow P_4O_{10}$$

  - React tetraphosphorus decoxide with water to make phosphoric acid.

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

Sample Calculations (1)

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?
- Beginning of unit analysis setup.

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg}} \text{ P} \left(\frac{\quad}{1 \cancel{\text{kg}}} \right)$$

- The formula for P_4O_{10} provides us with a conversion factor that converts from units of P to units of P_4O_{10}.

$$\frac{1 \text{ molecule } P_4O_{10}}{4 \text{ atoms P}}$$

Goal: To develop conversion factors that will convert between a measurable property (mass) and number of particles

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg}}\text{ P}\left(\frac{\quad}{1\ \cancel{\text{kg}}}\right)$$

Measurable Property 1

↓

Number of Particles 1

↓

Number of Particles 2

↓

Measurable Property 2

Mass 1

↓

Number of Particles 1

↓

Number of Particles 2

↓

Mass 2

Molar Conversions

Mass 1
↓
Number of Particles 1
↓
Number of Particles 2
↓
Mass 2

Mass 1
↓
Moles 1
↓
Moles 2
↓
Mass 2

Our Calculation

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?
- Here are the general steps for our calculation.

Mass P → moles P → moles P_4O_{10} → mass P_4O_{10}

Our Calculation – Step 1

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

Mass P → moles P → moles P_4O_{10} → mass P_4O_{10}

- We can convert grams of P to moles of P using the molar mass of P, which comes from its atomic mass that is found on the periodic table.

$$\frac{30.9738 \text{ g P}}{1 \text{ mol P}} \quad \text{or} \quad \frac{1 \text{ mol P}}{30.9738 \text{ g P}}$$

Periodic Table

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H 1.00794																	2 He 4.0026
2	3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797
3	11 Na 22.9898	12 Mg 24.3050											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
4	19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.9380	26 Fe 55.845	27 Co 58.9332	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9058	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.95	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.9045	54 Xe 131.29
6	55 Cs 132.9054	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (269)	109 Mt (268)	110 Ds (281)	111 Rg (272)	112 Cn (285)	113 Uut (284)	114 Fl (289)	115 Uup (288)	116 Lv (292)	117 Uus (297)	118 Uuo (294)

6	57 La 138.9055	58 Ce 140.115	59 Pr 140.9076	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.9253	66 Dy 162.50	67 Ho 164.9303	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04
7	89 Ac (227)	90 Th 232.0381	91 Pa 231.0359	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

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Our Calculation – Step 1

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

$$\text{Mass P} \longrightarrow \text{moles P} \longrightarrow \text{moles } P_4O_{10} \rightarrow \text{mass } P_4O_{10}$$

- Before we can convert grams P to moles P, we need to convert kg to g.

Converts given mass unit into grams.

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \text{ kg P} \left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}}\right)$$

Converts grams of element into moles.

Our Calculation

- The chemical formula provides a conversion factor for converting from moles of phosphorus atoms to moles of tetraphosphorus decoxide molecules in the second step of our calculation.

If $\frac{1 \text{ molecule } P_4O_{10}}{4 \text{ atoms P}}$ then $\frac{1 \text{ mol } P_4O_{10}}{4 \text{ mol P}}$

Our Calculation – Steps 1 and 2

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?
- Here are the first two steps in our calculation.

Converts given mass unit into grams.

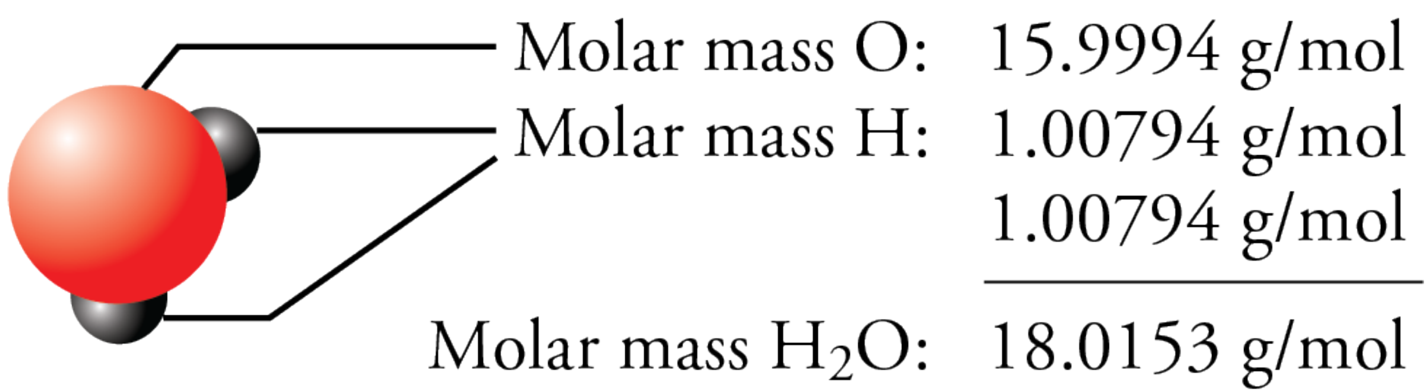
Converts moles of element into moles of compound.

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg P}} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mol P}}}{30.9738 \cancel{\text{g P}}}\right)\left(\frac{1 \text{ mol } P_4O_{10}}{4 \cancel{\text{mol P}}}\right)$$

Converts grams of element into moles.

Molecular Mass

- Whole = sum of parts
- mass of a molecule = sum of the masses of the atoms in the molecule
- **molecular mass** = the sum of the atomic masses of the atoms in the molecule



Periodic Table

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5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9058	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.95	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.9045	54 Xe 131.29
6	55 Cs 132.9054	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (269)	109 Mt (268)	110 Ds (281)	111 Rg (272)	112 Cn (285)	113 Uut (284)	114 Fl (289)	115 Uup (288)	116 Lv (292)	117 Uus (297)	118 Uuo (294)

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7	89 Ac (227)	90 Th 232.0381	91 Pa 231.0359	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

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Molar Mass For Molecular Compounds

- ***Molecular Mass*** = Sum of the atomic masses of the atoms in one molecule

$$\left(\frac{(\text{molecular mass})\,\text{g molecular compound}}{1\,\text{mol molecular compound}}\right)$$

Our Calculation

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

$$\text{Mass P} \longrightarrow \text{moles P} \longrightarrow \text{moles } P_4O_{10} \rightarrow \text{mass } P_4O_{10}$$

- We can now take the next step in our calculation using the molar mass of P_4O_{10} that comes from its molecular mass to convert from mol P_4O_{10} to g P_4O_{10}.

4(30.9738) + 10(15.9994) = 283.889 (with the correct rounding)

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \text{ kg P} \left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}}\right)\left(\frac{1 \text{ mol } P_4O_{10}}{4 \text{ mol P}}\right)\left(\frac{283.889 \text{ g } P_4O_{10}}{1 \text{ mol } P_4O_{10}}\right)$$

Periodic Table

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
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Our Calculation

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

  Mass P $\longrightarrow$ moles P $\longrightarrow$ moles P_4O_{10} $\rightarrow$ mass P_4O_{10}

- We can now complete our calculation by converting grams to kilograms.

Converts given mass unit into grams.

Converts moles of element into moles of compound.

Converts grams into desired mass unit.

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg P}} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mol P}}}{30.9738 \cancel{\text{g P}}}\right)\left(\frac{1 \cancel{\text{mol } P_4O_{10}}}{4 \cancel{\text{mol P}}}\right)\left(\frac{283.889 \cancel{\text{g}}\ P_4O_{10}}{1 \cancel{\text{mol } P_4O_{10}}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{\text{g}}}\right)$$

$$= \mathbf{2.50 \times 10^4 \text{ kg } P_4O_{10}}$$

Converts grams of element into moles.

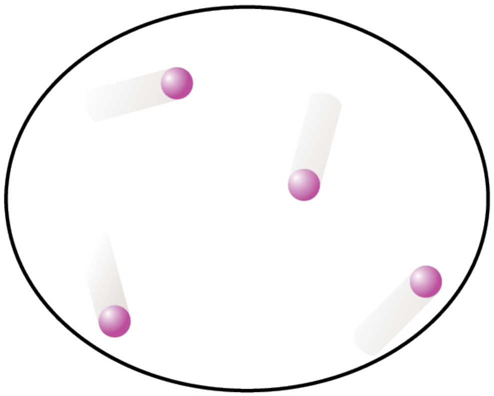
Converts moles of compound into grams.

Formula Units

- A ***formula unit*** of a substance is the group represented by the substance's chemical formula, that is, a group containing the kinds and numbers of atoms or ions listed in the chemical formula.
- Formula unit is a general term that can be used in reference to elements, molecular compounds, or ionic compounds.

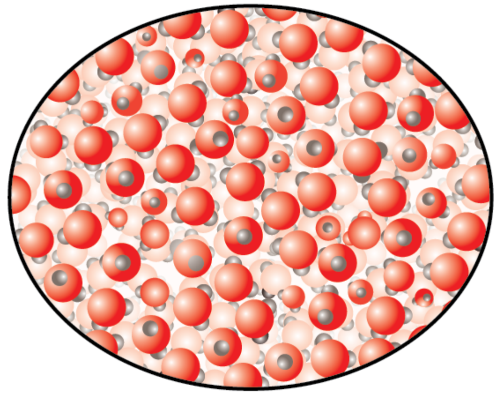
Formula Unit Examples

neon gas
(element)



A formula unit of neon contains one Ne atom.

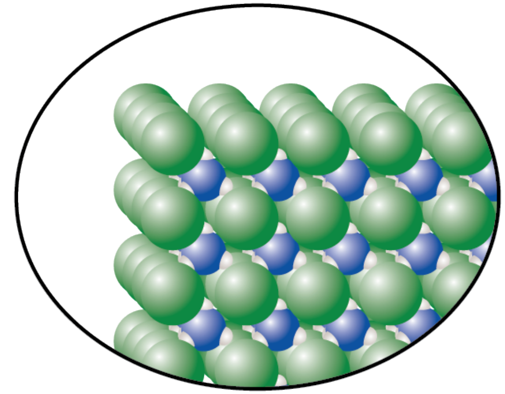
liquid water
(molecular compound)



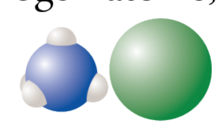
Liquid water is composed of discrete H_2O molecules.

A formula unit of water contains one oxygen atom and two hydrogen atoms.

ammonium chloride
(ionic compound)

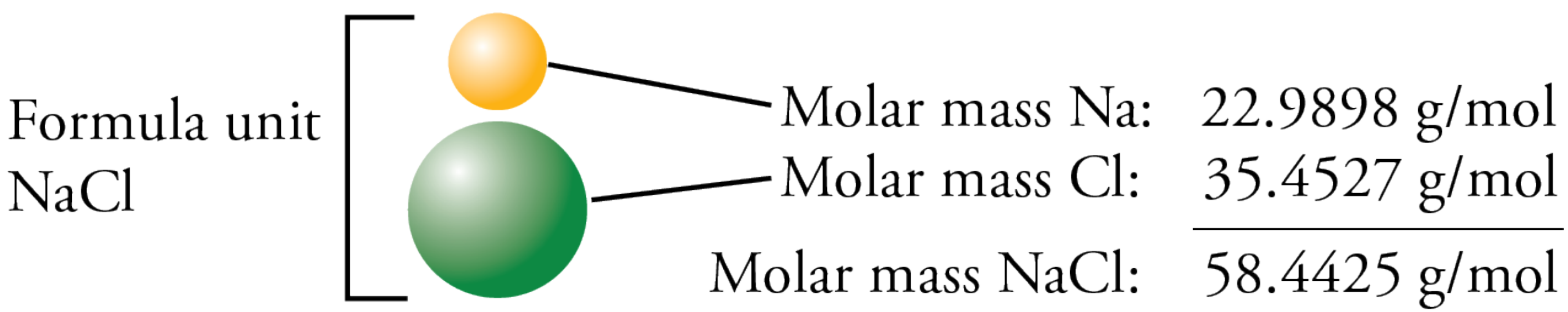


There are no separate ammonium chloride, NH_4Cl, molecules. Each ion is equally attracted to eight others.
A formula unit of ammonium chloride contains one ammonium ion, NH_4^+, and one chloride ion, Cl^-, (or one nitrogen atom, four hydrogen atoms, and one chloride ion).



Formula Mass for Ionic Compounds

- Whole = sum of parts
- Mass of a formula unit = sum of the masses of the atoms in the formula unit
- ***Formula mass*** = the sum of the atomic masses of the atoms in the formula



Periodic Table

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1										1 H 1.00794								2 He 4.0026
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3	11 Na 22.9898	12 Mg 24.3050											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
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Molar Mass For Ionic Compounds

- ***Formula Mass*** = Sum of the atomic masses of the atoms in a formula unit

$$\left(\frac{(\text{formula mass})\ \text{g ionic compound}}{1\ \text{mol ionic compound}} \right)$$

Periodic Table

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
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