UNIVERSITE Concordia UNIVERSITY

Answer key

| | | | |
|---|---|---|---|
| **Course:** CHEMISTRY | **Number:** 205/4 | **Section:** 03 and 04 | |
| **Instructors:** P.H. Bird, C.W. Rogers | | | |
| Examination: Final | **Date:** 14th April, 2008 | **Time:** 14:00 - 17:00 | **# of pages:** 15 |
| **Materials Allowed:** A data sheet and periodic table are attached to this paper - *no other materials are allowed.* You may tear off the data sheet and periodic table if you wish. | | | |
| **Calculators Allowed:** Yes (But cell phones or electronic dictionaries may NOT be used as calculators.) | | | |
| **Special Instructions:** This exam contains three sections. ***Please read the instructions before each section carefully.*** | | | |

LAST NAME: _____ FIRST NAME: _____

STUDENT NUMBER: _____ SIGNATURE: _____

## PLEASE READ THIS PAGE WHILE YOU WAIT TO START.

- ***Check that you have 15 pages including this page. Please write your ID # on all pages.***
- ***A periodic table and "useful information" are provided; you CAN remove those pages.***
- ***Non-programmable calculators are allowed; cell phones & electronic dictionaries are not.***
- ***Read ALL questions carefully BEFORE starting the exam, and answer ALL questions.***
- ***Write all answers in the space provided (use the backs of the pages for rough work).***
- ***SHOW YOUR WORK FOR ALL CALCULATIONS, or you will NOT get full marks.***

**GOOD LUCK! PLEASE RAISE YOUR HAND IF YOU NEED CLARIFICATION.**

**Please leave this area blank**

graded on /89

max 90.

**Section I. The following 20 questions are multiple choice. They are worth 2 marks each. You may do rough work on your exam paper, but it will not be marked. You *must* mark your answers *using a soft pencil* on the machine readable answer form provided. *Do not forget to mark your name and student number (your birth date is not required).***

1. All of the following processes are chemical properties of sodium, ***except:*** Physical

   i. C It's freshly cut shiny surface turns black on exposure to air.

   ii. P It is a solid at 25 °C, but changes to a liquid at 98 °C.

   iii. C When a small piece is placed in water, it sizzles, and a gas is formed.

   iv. C When exposed to chlorine gas it forms a compound which melts at 801 °C.

   v. P Its vapour (for example, in streetlights) emits yellow light when an electric current is passed through it.

   a. (iii) and (iv)

   b. (i) and (v)

   c. (ii) and (v)

   d. (ii), (iv) and (v)

   e. (iii), (iv) and (v)

A student gradually heats some tap water in a beaker in the lab. When the water reaches 30 °C bubbles slowly begin to form on the walls of the beaker and eventually float to the surface. At 100 °C bubbles are forming rapidly throughout the water as it boils. Which of the following statements describes the composition of the bubbles at the lower temperature, and at the boiling point?

| | bubbles **At 30 °C** | bubbles **At 100 °C** |
|---|---|---|
| a. | $H_2O$ (g) ✓ | $H_2$ (g) + $O_2$ (g) |
| b. | $H_2O$ (g) ✓ | $OH^-$ (g) + $H^+$ (g) |
| c. | Mostly $O_2$ (g) and $N_2$ (g) and some $H_2O$ (g) ✓ | $H_2O$ (g) |
| d. | $H_2O$ (g) ✓ | Mostly $O_2$ (g) and $N_2$ (g), and some $H_2O$ (g) |
| e. | CO (g) + $O_2$ (g) | $CO_2$ (g) |

3. An ion of aluminum-26, $Al^{3+}$ has:

   $^{26}_{13}Al - 3e^- = Al^{3+}$

   a. 13 protons, 13 neutrons, and 13 electrons neutral

   b. 13 protons, 10 neutrons, and 26 electrons

   c. 13 protons, 13 neutrons, and 16 electrons 3- anion

   d. 10 protons, 13 neutrons, and 13 electrons

   e. 13 protons, 13 neutrons, and 10 electrons 3+ cation

   $13p^+$ $13n^0$ $10e^-$

4. Which pair of elements would be most likely to form an ionic compound with each other?

M + NM

a. ✗ Phosphorus and Bromine

b. ✗ Zinc and Potassium

c. Fluorine and aluminum

d. ✗ Carbon and sulphur

e. ✗ Titanium and zinc

5. Which of the following statements does ***not*** correctly describe the reaction between sodium carbonate and hydrochloric acid?

$Na_2CO_3 + 2HCl \rightarrow H_2CO_3 + 2NaCl$

$H_2CO_3 \rightarrow H_2O + CO_2(g)$

a. ✓ The reaction can be classified as an acid-base reaction.

b. The reaction would not be visibly obvious. BUBBLES!

c. ✓ The sodium ions would be described as spectator ions. ✓

d. ✓ The reaction involves the evolution of gas. ✓

e. None – all of the above statements are true.

6. Complete the following sentence: Atoms emit electromagnetic radiation including visible light:

a. ✗ when electrons in atoms jump from lower to higher energy levels. absorb E

b. ✗ when atoms condense from a gas to a liquid

c. ✗ when electrons in atoms move across nodes in atomic orbitals

d. when electrons in atoms fall from higher to lower energy levels.

e. ✗ when electrons fall into the nucleus and are captured by protons.

7. In an electron microscope, electrons are accelerated to high velocities and have associated wavelengths suitable for "viewing" very small objects. What is the wavelength associated with an electron moving at $7.0 \times 10^6$ m $s^{-1}$? ( The mass of the electron is $9.11 \times 10^{-28}$ g)

a. $1.0 \times 10^{-13}$ m worth 1 point.

b. $1.0 \times 10^{-7}$ m

c. 1.0 m

d. $1.0 \times 10^{-10}$ m

e. $1.0 \times 10^{13}$ m

$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ kg\ m^2\ s^{-1}}{\left(\frac{9.11 \times 10^{-28}\ g}{1000\ kg}\right)(7.0 \times 10^6\ m\ s^{-1})}$

$= 1.039 \times 10^{-10}$ m

$= 1.0 \times 10^{-10}$ m.

8. Which diagram correctly represents the ground state electronic configuration of oxygen?

O : $1s^2 2s^2 2p^4$

| | 1s | 2s | 2p | |
|---|---|---|---|---|
| a. | ↑↓ | ↑↓ | ↑ ↑ ↑ | × GS |
| b. | ↑↓ | ↑↓ | ↑↓ ↑↓ | not GS |
| c. | ↑↓ | ↑↓ | ↑↓ ↑ | × not GS |
| d. | ↑↓ | ↑↓ | ↑↓ ↑ ↑ | GS! |
| e. | ↑↓ | ↑↓ | ↑↓ ↑↓ ↑ | × GS |

9. Consider each of the configurations shown in question 8. Which are ***not*** ground states according to Hund's rule?

a. Configurations a, c, d and e.
b. Configuration b only.
c. Configurations a, d and e.
d. Configuration a only.
e. Configurations b and c.

10. By what name are the elements of group 17 of the periodic table known?

↑ or $6p^7$

a. The chalcogens
b. The acid gases
c. The actinides
d. The halogens
e. The fluorinoids

11. An element has the following sequence of ionization energies:

$X \rightarrow X^+$ I.E. = 737 kJ $mol^{-1}$
$X^+ \rightarrow X^{2+}$ I.E. = 1450 kJ $mol^{-1}$ easy to lose $2e^-$
$X^{2+} \rightarrow X^{3+}$ I.E. = 7732 kJ $mol^{-1}$ hard to lose 3rd

Which of the following elements is it?

a. Hydrogen
b. Sodium
c. Magnesium
d. Aluminum
e. Argon

12. What kind of oxides would be compounds such as $NO_2$, $P_2O_5$, $SO_2$ etc. be?

NM oxides $SO_2 + H_2O \rightarrow H_2SO_3$ acid

a. Acidic oxides
b. Ionic oxides
c. Neutral oxides
d. Basic oxides
e. Bionic oxides

13. What is the $H^+$ concentration in hydrochloric acid with a pH of 2.30?

$pH = -\log[H^+]$

$[H^+] = 10^{-pH}$

$= 10^{-2.3}$

$= 5.0 \times 10^{-3}$

a. 2.30 M
b. 0.0050 M
c. $1.99 \times 10^2$ M
d. –2.30 M
e. 0.0030 M

14. Crystals of ionic compounds are held together by electrostatic forces. Which of the following statements characterize the potential energy associated with these forces?

a. Directly proportional to the product of the charges on the ions, and inversely proportional to the distance between them.
b. Directly proportional to the product of the charges on the ions, and directly proportional to the distance between them.
c. Inversely proportional to the product of the charges on the ions, and directly proportional to the distance between them.
d. Inversely proportional to the product of the charges on the ions, and directly proportional to the distance between them.
e. Directly proportional to the sum of the charges on the ions and directly proportional to the distance between them.

15. In the compounds indicated, which pair of elements would participate in the most polar covalent bond?

a. The two nitrogen atoms in H–N=N–H (g)
b. The two oxygen atoms in H–O–O–H (l)
c. The fluorine atoms in F–F (g)
d. Cesium and chlorine in CsCl (s) ionic ← worth 1 point
e. Silicon and carbon in $Cl_3Si–CH_3$ (l) ← correct (worth 2)

16. Two moles of nitrogen gas are heated from 20 °C to 350 °C while the volume is kept constant. How does the density of the nitrogen change?

$d = \frac{m}{V}$ ← constant; ↖ constant.

a. It stays the same.
b. It increases.
c. It decreases.
d. Because nitrogen is a gas, it has zero density.
e. There is not enough information given to answer the question.

17. What is the concentration of chloride ions in a solution prepared by dissolving 8.3 g of $CoCl_3$ in 125 mL of $H_2O$?

$CoCl_3 \rightarrow Co^{3+} + 3Cl^-$

conc. of compound ↑

$m = 8.3\,g$
$MM = 165.28\,g/mol$
$n = 0.05022$
× 3
$n = 0.15065$ in 0.125 L
$c = 1.2\,M$.

a. 0.019 M
b. 0.050 M
c. 0.15 M
d. 0.40 M ← worth 1 pt
e. 1.2 M ← correct (2 pt)

18. Which of the following diagram(s) represents orbital(s) where the quantum number, $\ell = 1$?

0 ⇒ s
1 ⇒ p
2 ⇒ d

(i) s (ii) p (iii) d (iv) d

a) Orbital (i)
b) Orbital (ii)
c) Orbitals (i) and (ii)
d) Orbitals (iii) and (iv)
e) All of them

19. Which of the classifications below apply to the reaction of copper(II) oxide with hydrogen?

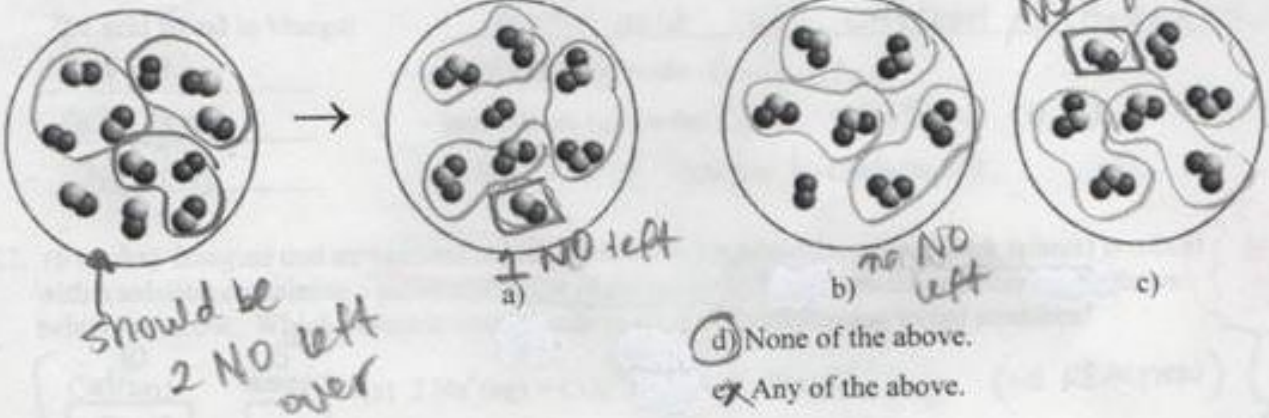
$CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(l)$

a) Acid – base
b) Precipitation
c) Oxidation reduction (redox)
d) Gas-forming
e) None of the above

20. Nitric oxide and oxygen react together to form nitrogen dioxide according to the reaction shown below:

$$2NO(g) + O_2(g) \rightarrow 2\,NO_2\,(g)$$

Consider the initial mixture of reactants shown below. Which of the outcomes shown after the reaction arrow best represents the reaction mixture after the reactants have reacted as completely as possible?




(d) None of the above.

(e) Any of the above.

You may use this space for rough work

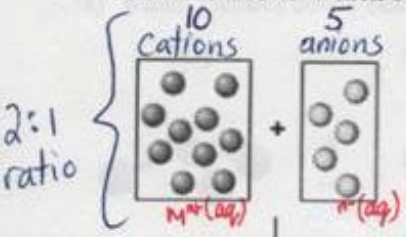
**Section II. The following 6 questions require short answers and should be answered in the space provided on this paper.**

21. (3 marks) Provide the missing name or formula for each substance below: 0.5 each (0.25 per ion/cation)

| | |
|---|---|
| $Fe_2(SO_4)_3$ $(Fe^{3+})_{x2}(SO_4^{2-})_{x3}$ | iron (III) sulfate OR ferric sulphate |
| $Na_2HPO_4$ $(Na^+)_{x2}$ $(HPO_4^{2-})_{x1}$ | sodium hydrogen phosphate |
| The acid found in vinegar | acetic acid OR $CH_3COOH$ / $C_2H_4O_2$ / $HC_2H_3O_2$ |
| $Cl_2O_7$ | dichlorine heptoxide (molecular) |
| $(NH_4)_2CO_3$ | ammonium carbonate (ionic $NH_4^+$ and $CO_3^{2-}$) |
| $NaHCO_3$ | "baking soda" OR sodium bicarbonate |

22. (6 marks) Imagine that an aqueous solution containing a particular cation (dark sphere) is mixed with a solution containing a particular anion (light sphere). Three possible outcomes are shown below the arrow. Which outcome corresponds to each of the following initial mixtures?

* Note: $H_2O$'s not shown!!



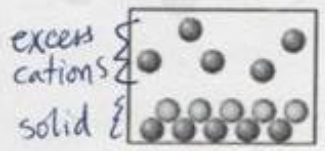

(a) $2\,Na^+(aq) + CO_3^{2-}(aq) \rightarrow$ $Na_2CO_3(aq)$ (NO REACTION)

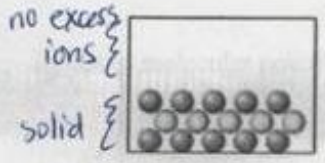
(b) $Ba^{2+}(aq) + CrO_4^{2-}(aq) \rightarrow$ $BaCrO_4(s)$ (PRECIPITATION)

(c) $2\,Ag^+(aq) + S^{2-}(aq) \rightarrow$ $Ag_2S(s)$ (PRECIPITATION)

not essential HERE.

- $H_2O$'s not shown
- phases ambiguous? → look like gases?


| Which initial mixture would give the outcome shown to the left? (2 each) | Explain briefly. |
|---|---|
| (a) $Na_2CO_3(aq)$ ✓ | • everything remains in solution ✓✓ i.e., no reaction occurred ✓✓ ⇒ $Na_2CO_3$ is a soluble salt ✓ (because alkali metal cation) |
| (b) $BaCrO_4(s)$ ✓ + excess $Ba^{2+}_{(aq)}$ | • precipitate with excess cations in supernatant solution ✓ ⇒ $BaCrO_4$ is an insoluble salt ✓ and only requires 1:1 ion ratio ✓ |
| (c) $Ag_2S(s)$ ✓ | • precipitate with no excess ions in solution ✓ ⇒ $Ag_2S$ is an insoluble salt ✓ and requires a 2:1 ion ratio ✓ ∴ all ions used up (no excess) |

• if wrong about solubility + products, max 0.5 each for reasonable state descriptions (interpreting pictures)

9 max.

23. (4 marks) Explain why sodium is a strong reducing agent. Provide one example of a balanced equation illustrating this behaviour.

not required to be terribly deep.

Define: reducing agent = species that causes reduction of other species via donating electrons (itself becomes oxidized) (1.0)

Explanation: (1.5) Sodium metal $Na_{(s)}$ is very good at doing this (losing electrons)

alkali metal...

$Na: \underbrace{1s^2 2s^2 2p^6}_{\text{core [Ne]}} 3s^1 \longrightarrow Na^+: 1s^2 2s^2 2p^6 + 1e^-$

$Z_{eff} \approx 11 - 10 \approx +1$ valence $e^-$ only held weakly by atom

noble gas configuration, very stable. $Z_{eff} \approx 11 - 2 = +9$ holding the $n=2$ electrons onto ion.

2.5

Examples: (1.5) balanced

$2\,Na_{(s)} + Cl_{2(g)} \longrightarrow 2\,NaCl_{(s)}$

$2\,Na_{(s)} + 2\,H_2O_{(l)} \longrightarrow 2\,NaOH_{(aq)} + H_{2(g)}$

24. (5 marks) When $SO_3$ gains two electrons, $SO_3^{2-}$ forms.

(a) Which pictures below best illustrates the change in molecular geometry around S? Why?

$SO_3$ $SO_3^{2-}$

A →

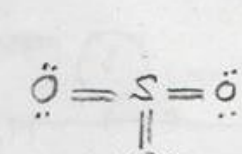
B →

C →

D →

4

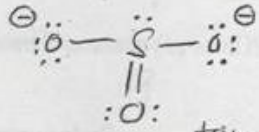
1



electron pair & observed: trigonal planar 1.5

3

Vs



electron pair: tetrahedral 1.5

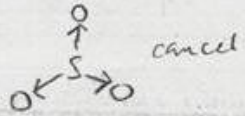
observed: trig. pyramidal

(b) Does molecular polarity change during this reaction? Explain briefly.

1

1

$SO_3$ planar ∴ non-polar

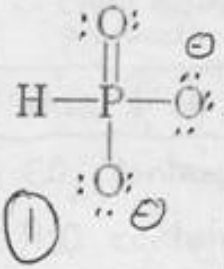


cancel

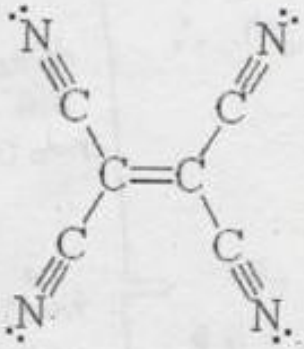
$SO_3^{2-}$ non-planar ∴ polar

do not cancel

25. (8 marks) For each of the diagrams below, mark in all the missing lone–pairs and formal charges where appropriate. *Do **not** change the number of bonds, and respect the charges on the species shown to their left.* Supply the information requested in the right-hand column.

| Charge | Lewis Structure | |
|---|---|---|
| zero |  (1) | (a) Electron pair (basic) geometry: Octahedral (1)<br>(b) Molecular (observed) geometry: square-pyramidal (1)<br>(c) Xenon hybridization: $sp^2d^2$ (1) |
| –2 |  (1) | (a) Total number of equivalent structures *including* this one: 3 (1)<br>(b) Average phosphorus oxygen bond order: $1\frac{1}{3}$ (1)<br>(c) Average charge on oxygen: $-\frac{2}{3}$ (1) |

26. (4 marks) The molecule tetracyanoethylene has been used in attempts to synthesis organic superconducting materials. Its structure is shown below.

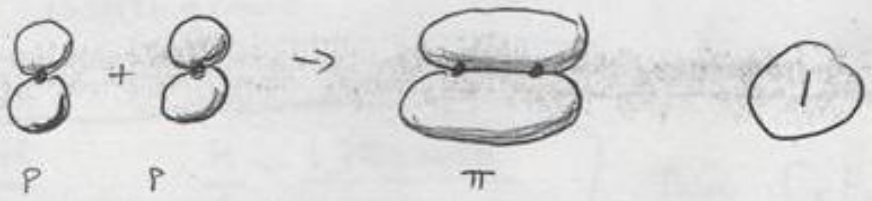


a) How many sigma (σ) bonds does it contain (in total)? 9 (1)

b) How many pi (π) bonds does it contain (in total)? 9 (1)

c) Is this molecule polar, or non-polar? non-polar (1)

d) Sketch how two p-orbitals overlap to form a π- bond. (1)



CR

**Section III. Answer the following 2 problems with *complete* written answers on the exam paper. Use the backs of the pages if you need more space. *Be sure to provide adequate explanations or details to justify your answers.***

↳ if not: (-3)

27. (8 marks) The foul odour of rancid butter is due largely to butyric acid, a compound containing carbon, hydrogen and oxygen. Combustion analysis of a 4.30 g sample of butyric acid produced 8.59 g of $CO_2$ and 3.52 g of $H_2O$. Find the empirical formula of butyric acid.

1.5

$$C_xH_yO_z + ?\,O_2 \xrightarrow[\text{yield}]{100\%} x\,CO_2 + \frac{y}{2}\,H_2O$$

| butyric acid | excess oxygen | carbon dioxide | water |
|---|---|---|---|
| $m = 4.30\,g$ | | $m = 8.59\,g$ | $m = 3.52\,g$ |
| ↑ composed of C, H + O atoms ∴ count them in the products... | | $MM = 44.01\ g/mol$ | $MM = 18.02\ g/mol$ |
| | | $\therefore \#n_{CO_2} = 0.1952\,mol$ ✓ | $\#n_{H_2O} = 0.1953\,mol$ ✓ |

calculated using $\#n = \frac{g}{MM}$

2

- Every C atom & H atom in products came from butyric acid ✓ (explanation)

  Every $CO_2$ contains 1 C ⇒ $\#n_C = \#n_{CO_2} = 0.1952$ mol C atoms ✓

  Every $H_2O$ contains 2H ⇒ $\#n_H = 2 \times n_{H_2O} = 0.3906$ mol H atoms ✓

- Butyric acid also contains oxygen atoms: weigh them by difference?

2 — Weigh the O atoms:

$m_{C_xH_yO_z} = m_C + m_H + m_O$ ✓ (explanation)

$\therefore m_O = m_{C_xH_yO_z} - m_C - m_H$

$= 4.30\,g - \left(0.1952\,mol_C \times 12.011\ g/mol\,C\right) - \left(0.3906\,mol_H \times 1.0079\ g/mol\,H\right)$ ✓

$= 4.30\,g - 2.345\,g - 0.3937\,g$

$m_O = 1.561\,g$ O atoms in sample ✓

+ Count them...

$\#n_O = \frac{1.561\,g\ O}{15.9996\ g/mol\ O} \doteq 0.09758$ mol O atoms ✓

(divide by $\#n_O$ since smallest of C, H, O... ∴ NORMALIZE ✓)

2.5

- Empirical formula = simplest mole ratio of elements ✓

$\frac{C}{O} = \frac{0.1952\,mol\,C}{0.09758\,mol\,O} \doteq \frac{2\,C}{1\,O}$ ✓

$\frac{H}{O} = \frac{0.3906\,mol\,H}{0.09758\,mol\,O} \doteq \frac{4\,H}{1\,O}$ ✓

Thus, $C_xH_yO_z = C_2H_4O$ ✓ //

8

28. (12 marks) Coal typically contains about 1.6 % sulfur by mass. When coal is burned, the sulfur is converted to sulfur dioxide. To prevent air pollution, coal-burning power plants treat this sulfur dioxide with calcium oxide (CaO) to form calcium sulfite ($CaSO_3$):

$$SO_2(g) + CaO(s) \rightarrow CaSO_3(s)$$

a) Show that the daily mass (in kg) of CaO needed by a power plant that uses $6.60 \times 10^6$ kg of coal per day is $1.8 \times 10^5$ kg.

Mass of Sulphur burned = $6.60\times10^6 \times \frac{1.6}{100} \times 1000 = 1.056\times10^8$ g (2)

$\therefore$ Moles of sulphur burned = $\frac{1.056\times10^8}{32.07} = 3.293\times10^6$ mol

Moles of Sulphur dioxide produced = moles of S burned

$= 3.293\times10^6$ mol (2)

Moles of CaO needed = moles $SO_2 = 3.293\times10^6$ mol (2)

Mass of CaO needed = $3.293\times10^6 \times (40.08+16.00)$

$= 3.293\times10^6 \times 56.08 = 1.847\times10^8$ g (2)

or $1.8\times10^5$ kg

Q.E.D

Poor explanation: upto −3
S.g.fig errors: upto −1

b) Without this treatment, what volume of $SO_2$ gas (at 25 °C and 1 atm) would have been emitted into the air per day?

Use $PV = nRT$ (1)

P pressure (atm) Volume (L)
T temp (°K) $R = 0.08206$ L.atm.mol$^{-1}$.K$^{-1}$
n = number of moles.

(Putting the correct things into formula) (1)

$V = \frac{3.293\times10^6 \times 0.08206 \times 298}{1} = 8\times10^7$ L (2)

Sig fig error: upto −2