Chemistry 423

Chem 423 Industrial Chemistry

Instructor Derek Leaist (dleaist@stfx.ca)
Office PSC 3072, Lab PSC 3020

Classes Tuesday 8:15 am, Wednesday 10:15 am, Friday 9:15 am (PS3046)

Course Notes **https://people.stfx.ca/dleaist/Chem423/**

Textbook None required. A list of library books, free online resources and suggested reading is provided.

Office Hours drop by or send an email anytime

What is Industrial Chemistry ?

large-scale economical production of

- basic chemicals (~ 20)
- chemical intermediates (~ 300)
- consumer products (~ 40,000)

from a few (~ 10) widely available and inexpensive naturally-occurring materials

The Industrial Chemistry "Tree"

Consumer Products (~ 40,000)

plastics, fibers, fertilizers, pharmaceuticals, paints, adhesives, detergents, solvents, ...

Chemical Intermediates (~ 300)

acetic acid, formaldehyde, urea, ethylene oxide, acrylonitrile, acetaldehyde, styrene, …

Basic Industrial Commodity Chemicals (~ 20)

H_2, CO, CO_2, NH_3, CH_3OH, H_2SO_4, H_3PO_4, HNO_3,Cl_2, NaOH, ethylene, propylene, butylenes, benzene, liquid fuels (gasoline, diesel, kerosene)

A Few Cheap Naturally-Occurring Raw Materials (~ 10)

air, water, petroleum, natural gas, coal, a few simple minerals (salt, limestone, sulfur…)

Analogy:

The Biochemistry Tree

Plants convert CO_2 , H_2O and small amounts of other naturally-occurring chemicals (containing N, P, S, *etc*.) into complex biochemicals:

- starches
- sugars
- lipids
- proteins
- alkaloids
- DNA …

Why Study Industrial Chemistry ?

The courses required for university chemistry degrees suggest the important chemistries are:

- physical
- analytical
- inorganic
- theoretical
- organic
- biochemical

But outside our world of university and academic chemistry, there is a **huge global chemical industry** worth exploring.

- different ways to do chemistry
- large scale and high production rates
- continuous flow processes preferred (not batch)
- **business chemistry**

an example …

BASF* Headquarters, Ludwigshafen, Germany

- 10 km^2 site on the Rhine River
- 200 integrated chemical plants
- 40,000 employees
- 10 million tonnes of products per year

*Ever heard of **BASF?**

- largest chemical producer in the world
- production facilities on every continent (except Antarctica)

Industrial Chemistry Reading and Resource Material:

Chemical and Engineering News ***(C&E News)***

- published weekly by the **American Chemical Society** **(largest scientific society in the world)**
- sample copy handed out
- ACS membership required, but student discounts are available
- covers all areas of chemistry, including basic research and industrial production
- job listings

StFXU Macdonald Library

Industrial Inorganic Chemistry 2nd Edition, K. H. Buchel, Wiley-VCH, 2002.

Industrial Organic Chemistry 5th Edition, H. J. Arpe, K. Weissermel, Wiley-VCH, 2010.

Kent and Riegel's Handbook of Industrial Chemistry and Biotechnology 11th Edition, J. A. Kent, E. R. Riegel, Springer 2007.

Ullman's Encyclopedia of Industrial Chemistry Wiley, online version.

Handbook of Industrial Chemicals. Organic Chemicals M. F. Ali, B. M. El Ali, J. G. Speight, McGraw Hill, online version.

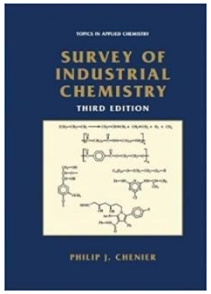
C423 Course Material https://people.stfx.ca/dleaist/Chem423/

Course Notes

C423_Introduction.pdf
C423_Part1_Inorganics.pdf
C423_Part2_Electrochemicals.pdf
C423_Part3_Petrochemicals.pdf
C423_Part4_Polymers.pdf
C423_Part5_Surfactants.pdf

P. J. Chenier, *Survey of Industrial Chemistry*, 3rd Ed., Kluwer Plenum 2002

C423_Survey_of_Industrial_Chemistry_PJ_Chemier.pdf



also available online:

http://fcebichivirtuallibrary.info/ebooks/Chem/P.J.Chenier-_Survey_of_Industrial_Chemistry.pdf

Top 50 Chemical Companies

A. H. Trullo, Global Top 50, *C&E News*, 30 July 2018

C423_Top_50.pdf

Industrial Chemistry Outlook

M. Bomgardner, World Chemical Outlook, *C&E News*, 9 Jan. 2018

C423_Chemical_Outlook _2018.pdf

Handouts in class.

Chem 423 Course Outline

Introduction

Part 1. Primary Inorganic Chemicals

Part 2. Industrial Electrochemistry

Part 3. Petroleum Refining and Petrochemicals

Part 4. Industrial Polymers

Part 5. Surfactants

Part 6. In-Class Presentations

Chem 423 Marking Scheme

assignments (about ten)	15 %
term tests (two, 15 % each)	30 %
in-class presentation	09 %
final exam	46 %
	100 %

term tests: **Tuesday 11 February, 8:00 am**

(in class) **Tuesday 17 March, 8:00 am**

final exam: date TBA (April exam period)

Why Study Industrial Chemistry ?

The main university chemistry courses are:

- physical
- analytical
- inorganic
- theoretical
- organic
- biochemical

Another important but often overlooked branch of chemistry:

- industrial chemistry

a few points to ponder …

1. **Industrial chemistry introduces an important variable not included in university chemistry studies:**

$ $ $ $ $

If you can synthesize and purify a gram of product on a university lab bench, can you **scale up** to thousands of tonnes per day?

Are the **costs** of research, development, startup and production **economical**?

Large-scale continuous flow processes for efficient production?

2. **Industrial chemistry ("business" chemistry) introduces other real-world considerations not usually included in university chemistry studies:**

- **financing and accounting**
- **patents and licensing**
- **management**
- **sales and marketing**
- **personnel**, human resources, unions
- **competition** from other companies
- **pollution/environmental regulations**
- **politics**

3. Global importance: money speaks

Industrial chemical production is valued at about **6 trillion dollars** per year and is growing steadily.

Canada	60 billion $USD
USA	890 billion
South America	310 billion
Western Europe	1,140 billion
Russia/Eastern Europe	170 billion
Africa/Middle East	190 billion
Asia/Pacific	2,950 billion
Global Total	**5,710 billion $USD**

4. Help wanted, careers available

- 2/3 of all chemists work in the chemical industry
- industrial chemistry illustrates important practical applications of university chemistry courses
- many university chemistry departments have strong collaborations with chemical industries
- many industrial chemical companies (all of the big ones) have active R&D (research and development) divisions
- many university chemists serve as (highly) paid consultants for chemical companies

5. Industrial chemistry has changed history and the way we live

examples:

- WWI is sometimes called the “Chemists’ War”. New methods for making explosives, ammunition, fuels and agricultural fertilizers for food production extended the War for years.
- Many historians believe the outcome of WWII was decided by the vast unimpeded industrial production of steel, gasoline, fuel oil, armaments, ships, aircraft, food, … in North America.
- More recently, the production of concrete, steel, plastics, synthetic rubber, textiles, natural gas, gasoline, other liquid fuels, paper, pesticides, drugs, detergents, and many other consumer products has changed the way we live.
- Most of the 7.6 billion people alive today would starve without the industrial production synthetic agricultural fertilizers.

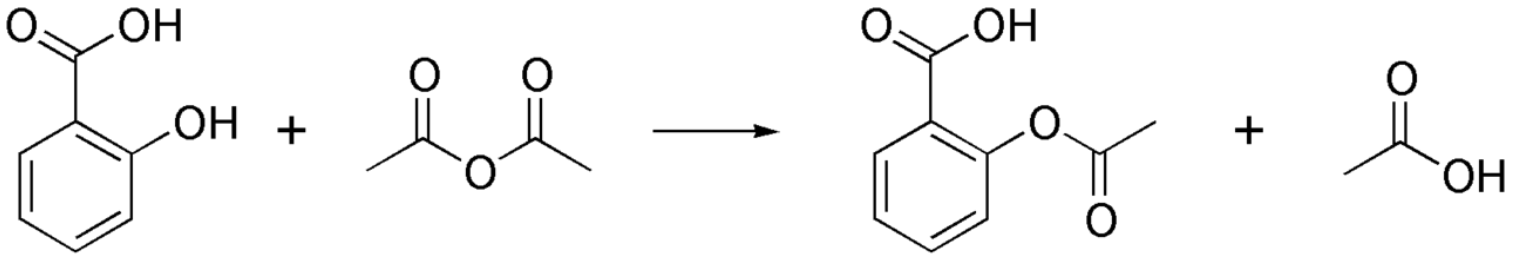
6. Industrial Chemistry is a useful general knowledge course

- What's that stench hanging over New Glasgow?
- What is hydraulic fracturing ("fracking")? Why has it become important in recent years for natural gas and petroleum production? What chemicals are used to frack?
- Is an electric car with a hydrogen fuel cell powered by the reaction $H_2 + ½O_2 = H_2O$ really pollution-free and carbon neutral (no CO_2 emitted)?
- ***Where do the products we use every day come from ?***

Example: **Aspirin** (ASA, acetylsalicylic acid)

Salicylic acid and its derivatives from willow-tree bark have been used for millennia to treat fever, arthritis, headaches, pain ...

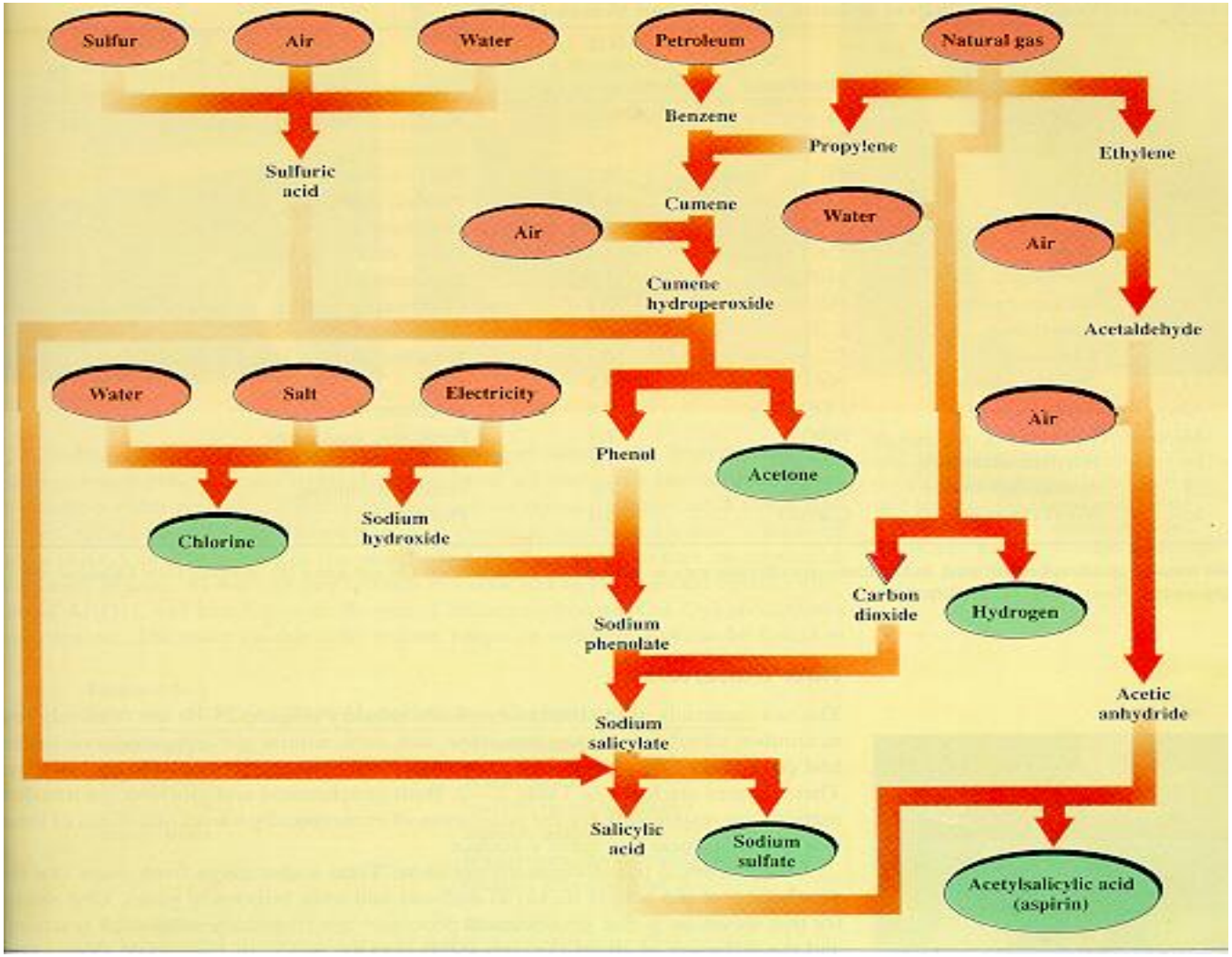
Aspirin (an important **NSAID**, nonsteroidal anti-inflammatory drug) can be made by extracting salicylic acid from tree bark and reacting it with acetic anhydride:



But this is **too slow and too expensive** to satisfy global demand, **100 billion aspirin doses per year**, value about 2 billion dollars.

And no willow trees would survive !

Instead, **Aspirin is produced industrially using air, water, sodium chloride, natural gas, petroleum and sulfur.**



100 tablets, 0.325 g aspirin per tablet, 32.5 g total aspirin

= $6.75 (amazon.ca)

= $0.208 per gram of aspirin

= $208 per kilogram of aspirin

= $208,000 per tonne of aspirin

in a consumer product

7. Industrial chemistry is primary production

Chemical industries convert relatively inexpensive materials existing in nature to **commercial value-added products**.

In addition to providing products essential for "modern life", the chemical industry is important economically. It pays large taxes and is **primary production** that creates and supports secondary service industries **(the "*build it and they will come*" multiplying factor)**:

- engineering, construction, machinery companies
- railroad, trucking, air and marine shipping
- plumbers, electricians, mechanics, technicians …
- Tim Hortons, retailers, bankers, veterinarians, doctors, dentists, lawyers, government employees, police, teachers, …

8. But industrial chemistry sounds really boring, about as interesting as a cement plant .

Ok, but "interesting" is subjective. Consider:

Cement and concrete (you'll know the difference after taking C423) **revolutionized the construction of roads, bridges, dams, buildings, skyscrapers …**

Remarkable **liquid rock** that pours, solidifies, and can outlast the Pyramids, costing as little as 15 cents per liter.

If you think cement and concrete are boring, go tell that to the builders of the Panama Canal, Hoover Dam, Empire State Building, Confederation bridge to PEI, the StFXU campus, …

Concrete and cement formulations, solidification processes, reinforcement with steel or fibers, anti-corrosion additives, *etc*. are under constant research and development.

concrete can be beautiful

Hoover Dam on the Colorado River

Constructed 1931-36. 2.5 million cubic meters of concrete. 70 stories tall. Provided flood control, water for agriculture, and electricity for southern California, especially Los Angeles. 112 construction workers died in accidents.

concrete can be beautiful

Confederation Bridge Linking NB and PEI

Constructed 1993-97. 0.5 million cubic meters of **special** concrete. 13 km long.

- Why **special** concrete?
- Why is the bridge curved?

9. But you're more interested in fundamental chemical research than industrial chemistry.

Ok, but consider:

- basic research in organic, inorganic and physical chemistry is essential for the development of new industrial processes
- **Nobel Prizes** have been awarded for industrial chemistry (*e.g.*, ammonia synthesis and ethylene polymerization to make polyethylene)
- **Alfred Nobel was an industrial chemist!**
- **funding for basic research is much more easily obtained nowadays if the research has practical applications**

10. A challenge:

Using your interest and training in chemistry, can you:

- make existing chemical processes more economical
- improve safety, reduce pollution
- work as a consultant for chemical companies
- make better products for consumers
- develop **new** chemical processes and **new** products
- start a company, providing good jobs

Where to Start? Top 50 Industrial Chemicals (by weight)

1. sulfuric acid
2. nitrogen
3. oxygen
4. ethylene
5. calcium oxide ("lime")
6. ammonia
7. phosphoric acid
8. sodium hydroxide
9. propylene
10. chlorine
11. sodium carbonate
12. methyl *tert*-butyl ether
13. ethylene dichloride
14. nitric acid
15. ammonium nitrate
16. benzene
17. urea
18. vinyl chloride
19. ethylbenzene
20. styrene
21. methanol
22. carbon dioxide
23. *m*-xylene
24. formaldehyde
25. terephthalic acid
26. benzene
27. hydrochloric acid
28. toluene
29. *p*-xylene
30. cumene
31. ammonium sulfate
32. ethylene glycol
33. acetic acid
34. phenol
35. propylene oxide
36. butadiene
37. carbon black
38. *iso*-butylene
39. potassium chloride
40. acrylonitrile
41. vinyl acetate
42. titanium dioxide
43. acetone
44. butyraldehyde
45. aluminum sulfate
46. sodium silicate
47. cyclohexane
48. adipic acid
49. nitrobenzene
50. bisphenol A

31 are **organic**, but more inorganic chemicals are near the top of the list (8 out of the top 10). **Inorganics dominate by weight and are considered first.**

C471 Part 1: Primary Inorganic Chemicals

1.1 water, purification and treatment

1.2 methane (***organic***, but obtained from natural gas, main source of H_2, CO, S)

1.3 hydrogen

1.4 carbon dioxide

1.5 oxygen **(*major industrial gases*)**

1.6 nitrogen

1.7 ammonia

1.8 nitric acid

1.9 sulfuric acid **(*major industrial acids*)**

1.10 phosphoric acid

1.11 calcium oxide (lime)

1.12 sodium carbonate **(*"limestone" chemicals*)**

1.13 concrete

1.14 iron and steel

Part 2: Industrial Electrochemistry

2.1 electrochemical cells – background

2.2 batteries

2.3 fuel cells

2.4 corrosion

2.5 sodium chloride

2.6 chloralkali products (Cl_2, NaOH, H_2 from aqueous NaCl electrolysis)

2.7 aluminum

2.8 copper refining

2.9 other electrochemical industries

Part 3: Petroleum Refining and Petrochemicals

3.1 petroleum refining, distillation and chemical processes

3.2 chemicals from methane

3.3 ethylene chemicals (C2 Fraction)

3.4 propylene chemicals (C3 Fraction)

3.5 chemicals from butylenes (C4 Fraction)

3.6 chemicals from benzene, toluene and xylenes (BTX)

Part 4: Industrial Polymers (short)

4.1 polymer terminology

4.2 the **Big Six** industrial polymers

4.3 step- and chain-growth polymerization

4.4 co-polymers

4.5 thermoset polymers

Part 5: Industrial Surfactants (short)

Part 6: Class Presentations

- **short presentations by members of the class**
- covering industrial chemistry topics of your choice and interest
- 20 minutes for each presentation, plus 5 minutes for questions from the class
- suggestions for giving good presentations will be provided
- the class presentations will be part of the course material
- examples of possible topics – next page
- ***other topics welcome***
- **please confirm your presentation topic choice with the instructor**

Possible C423 Presentation Topics (many other suitable topics)

abrasives (natural and synthetic)
adhesives
bromine
catalysts for industrial chemistry
coal (focus on Nova Scotia production?)
energetic materials (explosives)
fertilizers
fluorine
fracking (hydraulic fracturing)
graphite
hydrogen peroxide
lithium
nickel (focus on Canadian production?)
pesticides
pigments and dyes
potassium
silicones
textile fibers
uranium for nuclear fuel
zeolites

activated carbon, carbon black
Brierly Brook Water Treatment Plant
carbon capture
ceramics
elastomers (*e.g.*, synthetic rubber for tires)
fermentation and biomass products
fibers (for insulation, reinforcement)
food additives
gypsum (focus on Nova Scotia production?)
helium
iodine
mineral processing (*e.g.* flotation)
paints and coatings
pharmaceuticals (*e.g.*, antibiotics)
potash
pulp and paper (focus on Northern Pulp?)
Teflon®
titanium and titanium dioxide
urea
zinc