



INTERNATIONAL COLLEGE
OF PHARMACEUTICAL
INNOVATION

国际创新药学院

Physical and Chemical Properties of Solutions (I-III)

Course	BSc(Pharm) & BSc (ATT)
Year	2024-2025 II
Module	Medicines Pharmaceutics 2
Lecturer	Dr. Congcong Xu

LEARNING OUTCOMES

- | |
|--|
| 1. Describe the colligative properties (依数性) of solutions |
| 2. Describe the function of buffering in solution dosage forms |
| 3. Recognize the role of adsorption in pharmaceutical science |
| 4. Recall the role of optimal rheological 流变学 phenomena on solution dosage forms |
| 5. Predict how precipitation might occur due to physicochemical interactions |



RECOMMENDED READING

Physicochemical Principles of Pharmacy

Fourth edition

Alexander T Florence and David Attwood



2 Gases and volatile agents

35

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MARTIN'S Physical Pharmacy and Pharmaceutical Sciences

Seventh Edition



8 BUFFERED AND ISOTONIC SOLUTIONS

[thePoint](#) For additional ancillary materials related to this chapter, please visit [thePoint](#).

16 RHEOLOGY

[thePoint](#) For additional ancillary materials related to this chapter, please visit [thePoint](#).

Physicochemical Principles of Pharmacy

In Manufacture, Formulation and Clinical Use

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SOLUTIONS

- **SOLUTION**: A homogenous molecular dispersion of solute dissolved in solvent. The solute is typically the substance that undergoes a phase transition.

Phase 1	Phase 2	Formal state	Example
Gas	Gas	Gas solution	Air
Liquid	Gas	Vapour	Water vapour in air
Gas	Liquid	Liquid	HCl in water
Solid	Gas	Solid vapour	Iodine vapour in air
Gas	Solid	Solid	Co ₂ in steel
Solid	Liquid	Liquid solution	Aspirin in water
Solid	Solid	Solid solution	Griseofulvin 灰黄霉素 in succinic acid 琥珀酸
Liquid	Liquid	Liquid solution	Ethanol in water
Liquid	Solid	Solid solution	Mineral oil in paraffin wax 固体石蜡



CHARACTERISTICS OF SOLUTES IN SOLVENTS

- Solutes (drugs and excipients) interact with solvents to different extents depending on their physical and chemical properties

Characteristics	Non-electrolytes	Strong electrolytes	Weak electrolytes
Ionizability	No ions	Completely ionised	Weakly ionised, pH dependency
Conductivity	Do not conduct electricity	Conduct strong current	Conduct weak current
Colligative property	Depends on the number of molecules in solution	Depends on number of ions in solution	Depends on degree of ionisation
Pharmaceutical excipients	Dextrose右旋糖, mannitol甘露醇, glycerol	HCl, NaOH, NaCl, KCl	Acetic acid, citric acid, benzoic acid苯甲酸
Drugs	Carbamazepine立痛定, prednisone强的松, lovastatin洛伐他汀	Morphine sulphate, penicillin potassium, propranolol HCl	Morphine, penicillin, propranolol心得安



IDEALITY IN SOLUTIONS

- **Ideal solution**: Refers to complete uniformity of intermolecular forces in a solution. Thus, solvent/solvent, drug/drug and drug/solvent interactions are equal.
 - Thermoneutral (热中性的) dissolution (no heat is taken in or evolved in dissolution)
 - No shrinkage or expansion of the system
 - Structurally similar systems exhibit ideal behaviour (e.g. ethanol and methanol)
 - Surface tension, refractive index 折射率, viscosity, and vapour pressure are weighted averages of each pure substance
 - Complete uniformity
- **Real or non-ideal solution**: Most pharmaceutical solutions are non-ideal or real, in that the forces of interaction between solvent/solvent, drug/drug and drug/solvent interactions are unequal.



COLLIGATIVE PROPERTIES

- **Colligative property (依数性)**: The alteration of the properties of pure solvent (e.g. water) due to the number of solute species within the solution. These properties predominantly relate to the absolute number of species as opposed to the nature of the solute.
- Termed colligative because they are “*tied together*” by the underlying relationship to the concentration of dissolved species.
- The effect of a solute on one colligative property can be used to predict the actions on another colligative property.

Lowering of vapour pressure (蒸气压)

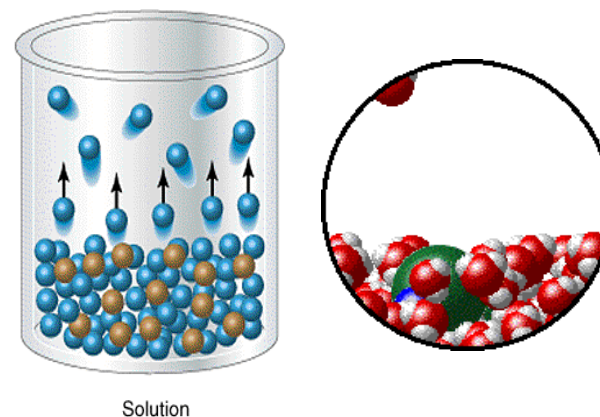
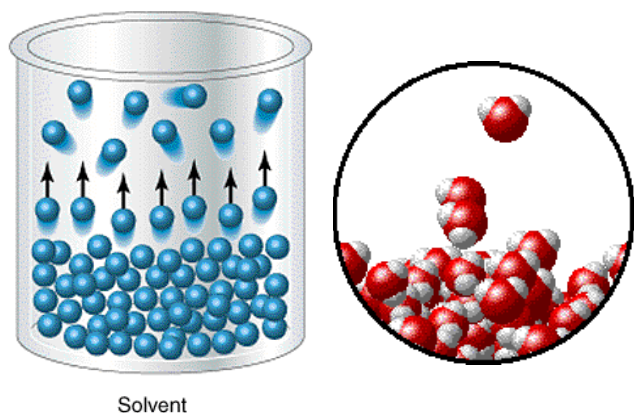
Boiling point elevation

Freezing point (凝固点) depression

Increased osmotic pressure (渗透压)



VAPOUR PRESSURE LOWERING



- Dissolution of a non-volatile solute in a solvent will reduce the vapour pressure of a liquid as the mole fraction increases
- When two volatile solvents are mixed the vapour pressure will be the sum of the weighted mean of each solvent

$$p_A = p_A^\circ X_A$$

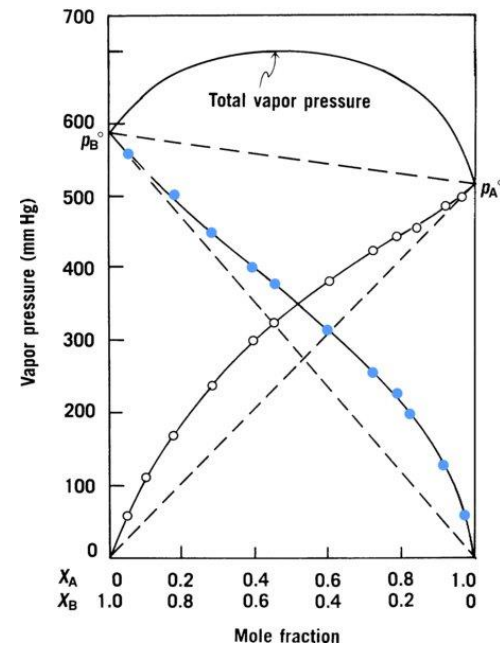
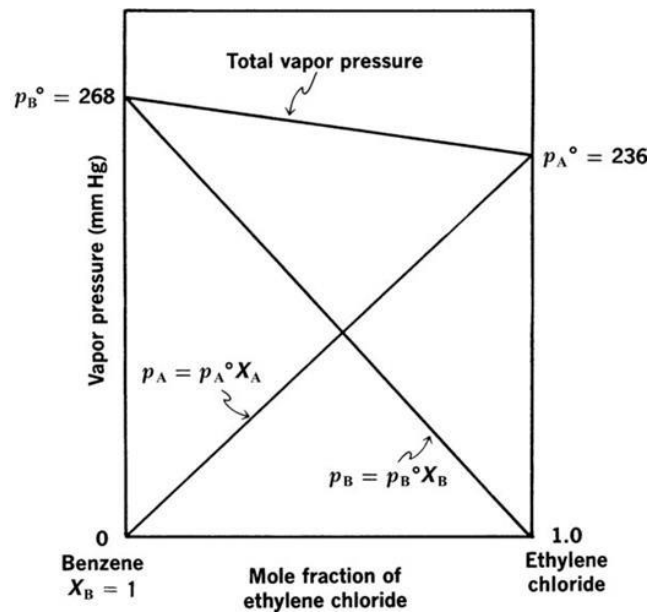
VAPOUR PRESSURE

Vapor Pressure and Boiling



VAPOUR PRESSURE OF VOLATILE LIQUID BLENDS

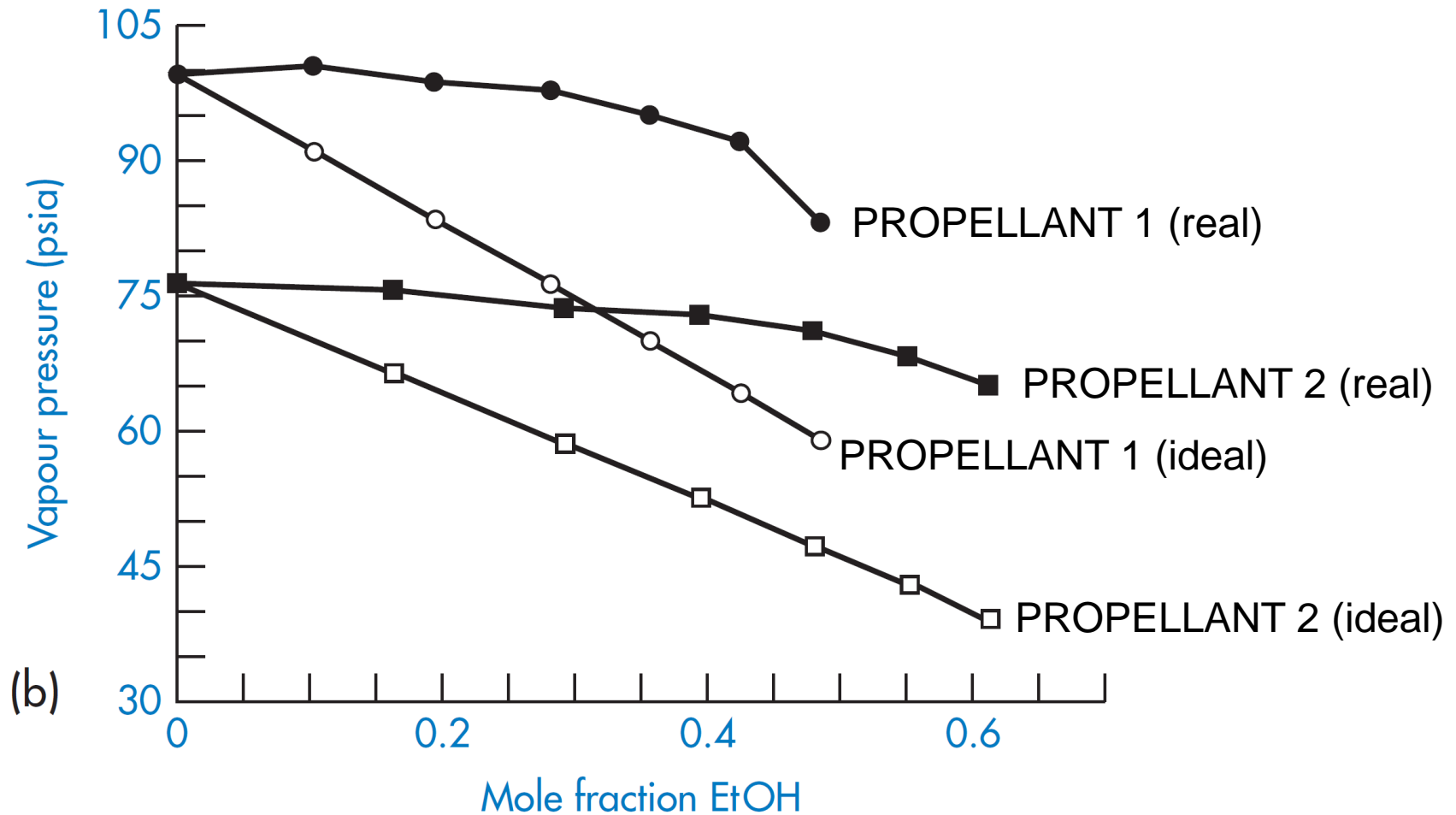
- Ideal substances obey Raoult's law 拉乌尔定律 (states the vapour pressure of a solution is proportional to the mole fraction of solvent)



In non-ideal situations, escaping tendency can be higher (positive deviation from Raoult's law) or lower (negative deviation from Raoult's law) than ideality



LOWERING VAPOUR PRESSURE



REAL SOLUTION
POSITIVE DEVIATION FROM RAOULT'S LAW



BOILING POINT ELEVATION

- Just as a solute lowers the vapour pressure (reduces evaporation), it will also elevate the boiling point of the solutions (anti-boil)

$$\Delta T_b = K_b m$$

ΔT_b = Elevated boiling point

K_b = Molal elevation constant

m = Molal concentration 质量摩尔浓度

FREEZING POINT DEPRESSION

- Just as a solute lowers the vapour pressure (reduces evaporation), it will also depress the freezing point of the solutions (anti-freeze)

$$\Delta T_f = K_f m$$

ΔT_f = Freezing point depression

K_f = Molal freezing point constant

m = Molal concentration



MOLARITY (摩尔浓度) VS MOLALITY (质量摩尔浓度)

Molality (m)

溶质物质的量 / 溶剂质量, Unit: mol/kg

公式: $m = n_{\text{溶质}} / m_{\text{溶剂}}$

Molarity (M)

溶质物质的量 / 溶液体积, Unit: mol/L

公式: $M = n_{\text{溶质}} / V_{\text{溶液}}$

1. Different Denominators (分母)
 2. Temperature dependence
- 质量摩尔浓度: Temperature-independent
摩尔浓度: Temperature dependent



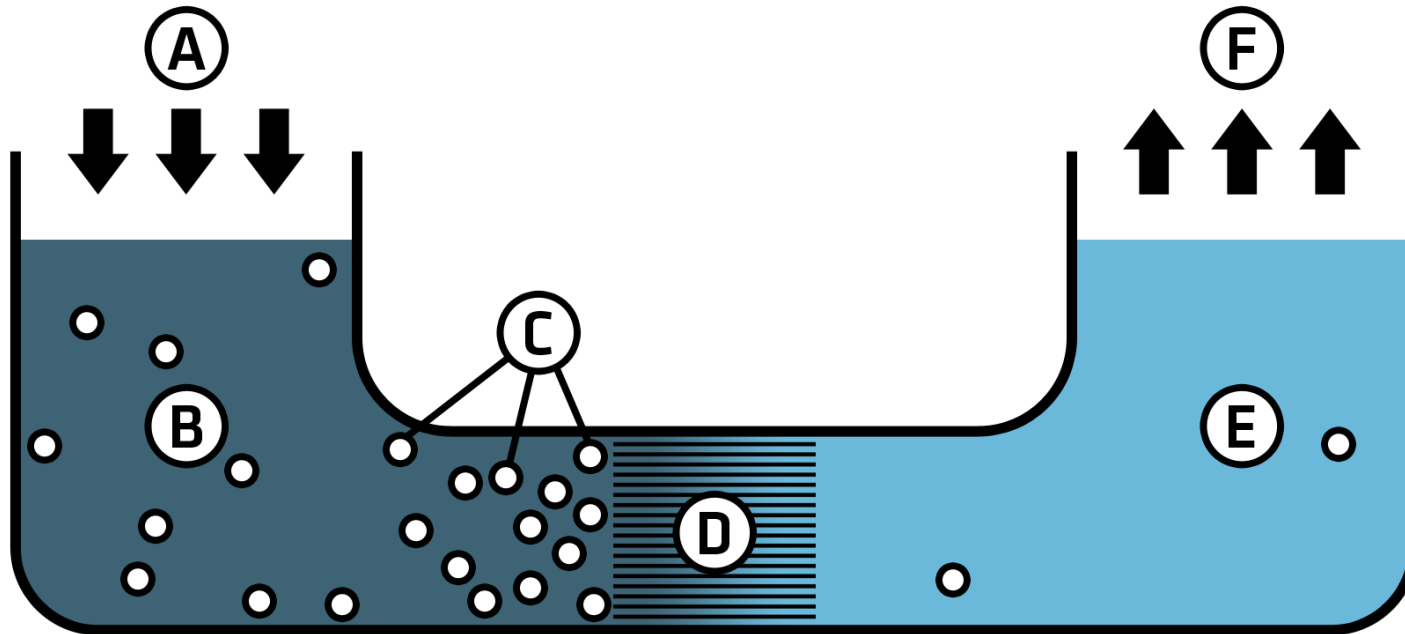
BOILING POINT ELEVATION AND FREEZING POINT DEPRESSION OF SOME SOLVENTS

Solvent	Boiling point	K_b (°C/m)	Freezing point	K_f (°C/m)
Water	100°C	+0.512°C/m	0°C	-1.86°C/m
Camphor樟脑	207°C	+5.166°C/m	179.75°C	-39.7°C/m



OSMOTIC PRESSURE

Pressure required to prevent osmosis



OSMOTIC PRESSURE 渗透压: The pressure that must be applied to a solution to prevent the movement of solvent into it when solution and solvent are separated by a semi-permeable membrane (Pressure due to the tendency of the solvent to move across a semi-permeable membrane from an area of low solute concentration to one of high concentration)



OSMOTIC PRESSURE

$$\pi = MRT$$

π = Osmotic pressure (atm)

M = Molar concentration of solution

R = Ideal gas constant

T = Absolute temperature (K)



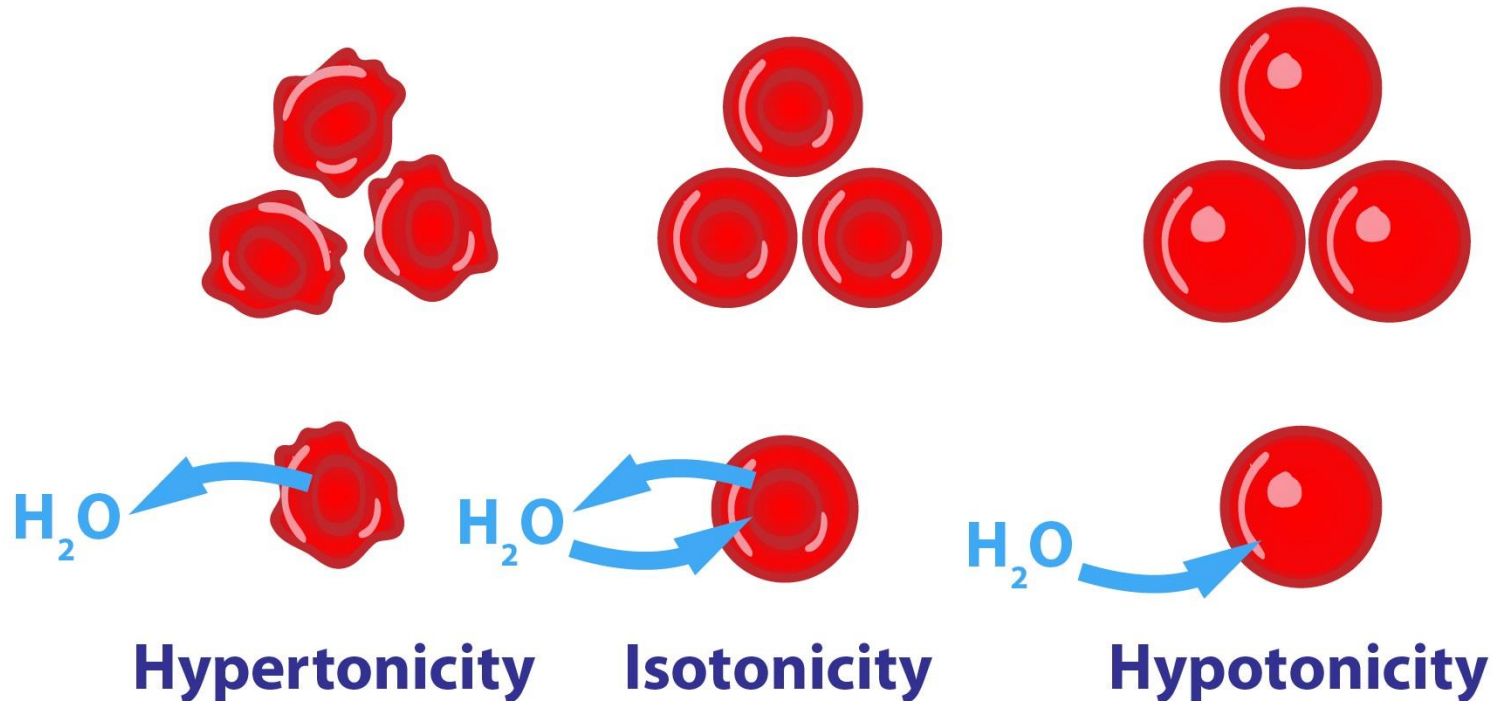
DIFFUSION VS OSMOSIS VS DIALYSIS



The diagram features a central light blue rectangular box with a 3D effect, containing the words "Diffusion", "Osmosis", and "Dialysis" in orange, bold, sans-serif font. The background is a dark blue field with a faint, light blue, irregular pattern resembling a cell membrane. Numerous spheres are scattered throughout: dark blue spheres are primarily in the upper half, and a mix of dark blue and reddish-brown spheres are in the lower half. The spheres vary in size and are semi-transparent, showing the background pattern through them.

Diffusion **Osmosis** **Dialysis**

TONICITY: OSMOTIC PRESSURE IN CELLS



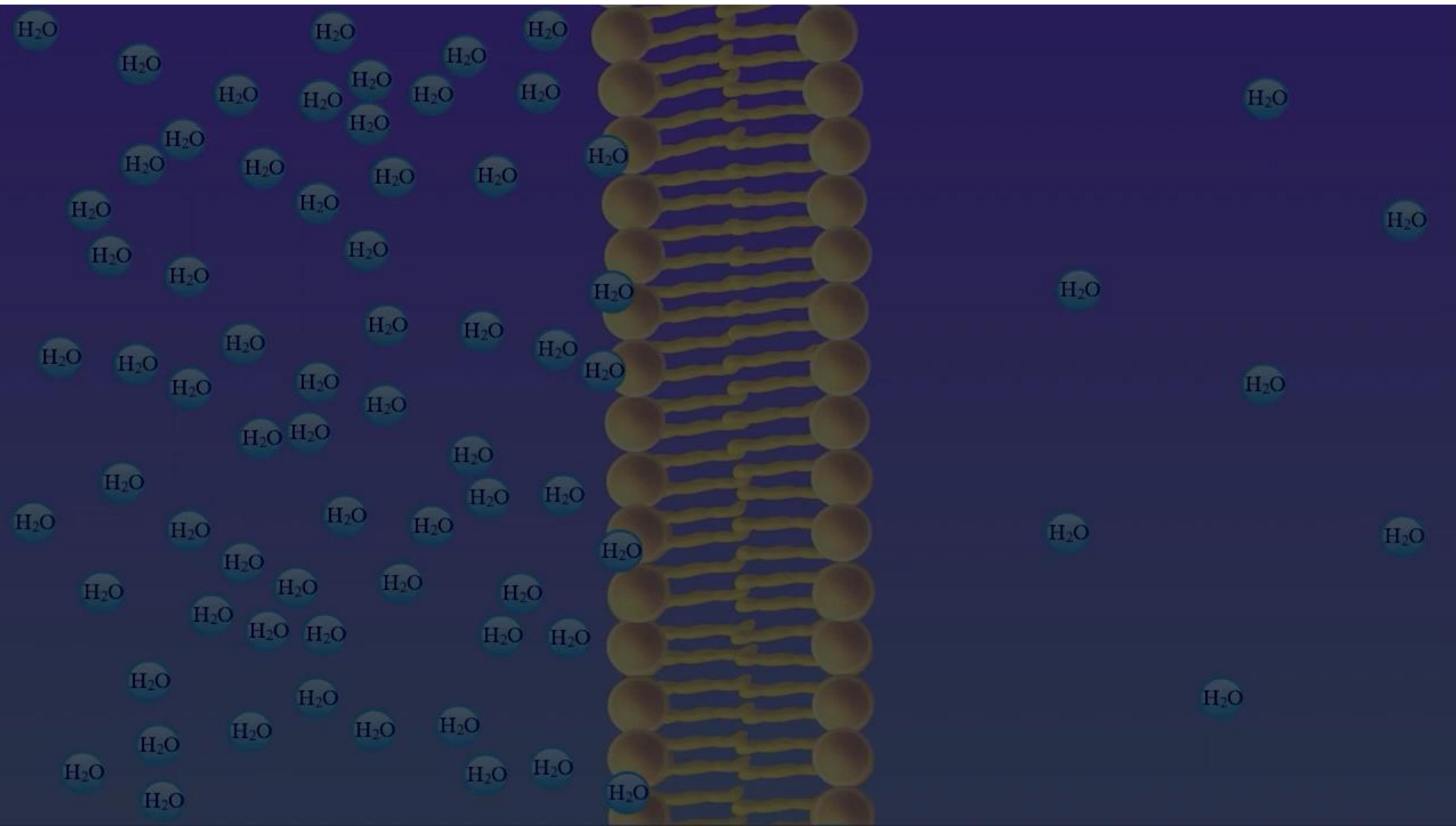
Isotonic等渗的: equal concentration of dissolved species inside the cell versus outside the cell

Hypertonic高渗的: Higher number of dissolved species outside cell versus inside the cell

Hypotonic低渗的: Lower number of dissolved species outside the cell versus inside the cell

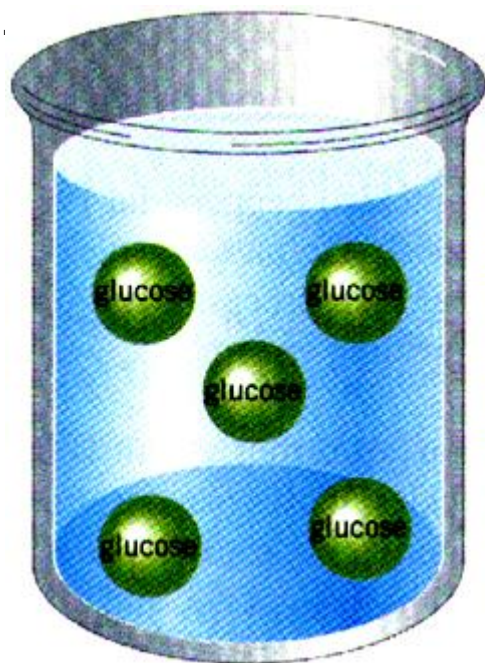


OSMOSIS ANIMATION



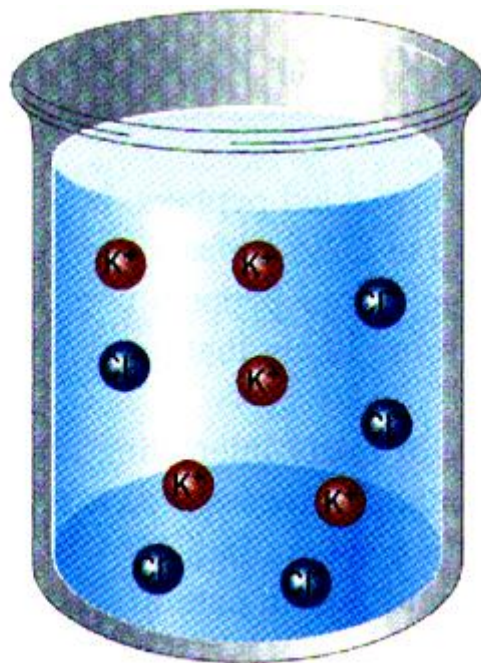
DISSOCIATION INFLUENCES COLLIGATIVE PROPERTY

- 1 M solution of a non-ionic species (e.g. Glucose葡萄糖) depresses the freezing point of water by 0.512°C , but a ionisable substance will dissociate (weakly or strongly) which influences the overall number of species in water



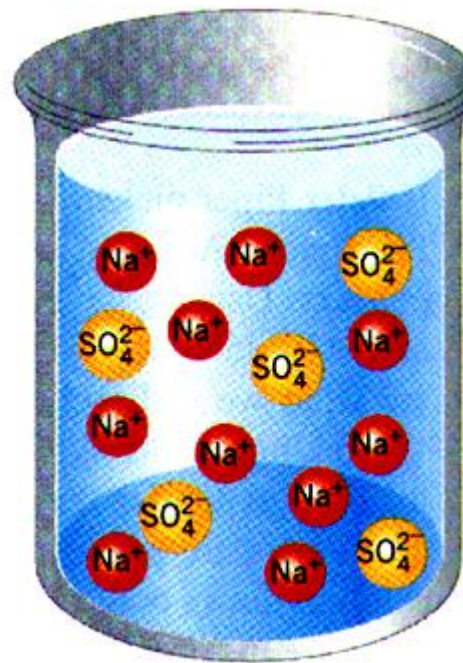
Glucose

1 SPECIES



KCl

2 SPECIES



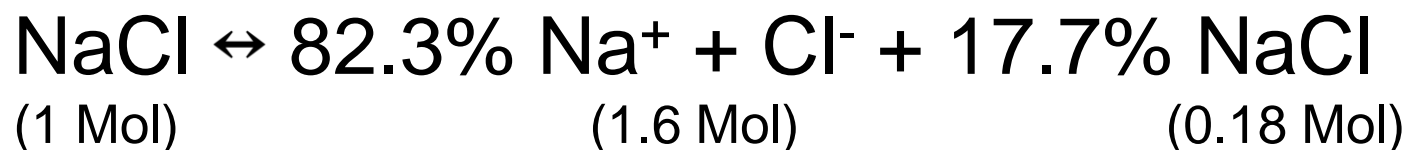
Na_2SO_4

3 SPECIES

COMPENSATING FOR IONIC SPECIES

Van't Hoff factor (*i*)

- i* factor**: factor which accounts for deviation of colligative property due to the electrolyte nature of the solute. The extent of ionisation varies for different solutes (e.g. acetic acid) and in cases where ionisation has occurred, solvated molecules can be strongly attracted oppositely charged solutes (ion pairing)



$$\pi = iMRT$$

- Included in formula to accurately determine colligative property

Electrolyte	Ideal	Measured
NaCl	2	1.9
MgCl ₂	3	2.7
AlCl ₃	4	3.2

PHARMACEUTICAL RELEVANCE OF COLLIGATIVE PROPERTIES

- Excessive consumption of solvent can be dangerous
- Blood has a balanced concentration of species and deviation can lead to a dangerous imbalance (isotonicity)
- Large volume solutions for ophthalmic眼科的 delivery must be isotonic
- Depression of freezing point plays a role in physiology of cold blooded animals
- Reducing vapour pressure can prevent formulations from drying out (humectants保湿剂)
- Important in the development of aerosols 气雾剂 (propellant selection)
- Prevent drug loss via vaporisation



DRUGS ALTER SOLUTION pH

- It is important to note that dissolution of acidic or basic drugs can significantly alter the pH of the solution. This can greatly influence physical, chemical and biological stability of the system
- In the case of drug salts this is a key goal of the formulation, but it is important to note that subsequent pH changes upon administration such as injection into blood can alter the physical state of the drug (e.g. precipitation)

		Drug	Quantity	Δ pH	Final pH
氨茶碱		Aminophylline	250 mg	+4.2	8.5
			500 mg	+4.2	8.5
头孢噻吩钠		Cefalothin sodium	1 g	+0.1	4.2
			2 g	+0.2	4.3
盐酸土霉素		Oxytetracycline hydrochloride	500 mg	-1.25	2.9
			1 g	-1.45	2.7

BUFFERING

- **BUFFER**: Solutions of weak acids (RCOOH) and their conjugate bases (RCOO^-Na^+) that resist changes in pH. Buffering capacity is defined with the Henderson Hasselbach equation. Buffers can be used to optimise solubility, permeability, stability

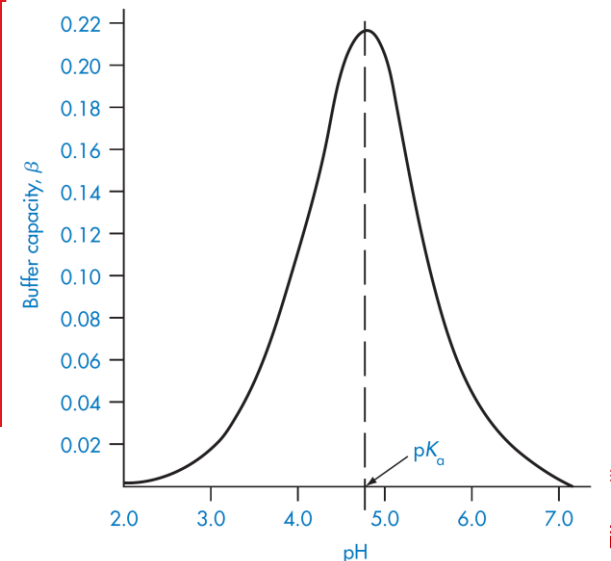
- **Buffering capacity**: is defined as amount of strong acid or strong base required to change the pH of 1L of buffer by 1 pH unit

$$\beta = \frac{dc}{d(\text{pH})}$$

- **Acetate buffer (acetic acid adjusted to its pKa 4.74)**

$[10\text{mM CH}_3\text{COOH}] + [10\text{mM CH}_3\text{COO}^-]$

In this solution, there are enough acid (CH_3COOH) and base (CH_3COO^-) forms to mop up (吸收) H^+ or OH^- ions in the solution and prevent any large changes in pH



BUFFER SELECTION

- Buffer pH is defined by the pKa and the ratio of acid to base
- Buffer capacity depends on the concentration of the buffer components
- The concentration of buffer should be sufficient to maintain pH of the dosage form without affecting the pH of the body compartment following administration (e.g. eye drops and irritation)
- Buffers are typically used between 0.05-0.5 M
- Safety considerations via route (Boric acid 硼酸 is toxic parenterally, but can be used in ocular delivery)
- Buffers made with amines have an odour and should not be used in oral dosage forms
- Used within 1 pH unit of their pKa
- HH Equation can be used to determine the ratio of acid to base
- Often a careful balance required to ensure solubility of all drugs and excipients



CONSIDERATIONS IN OPTIMISING BUFFERING CAPACITY

Chemical stability

Patient acceptability

Permeability

Solubility



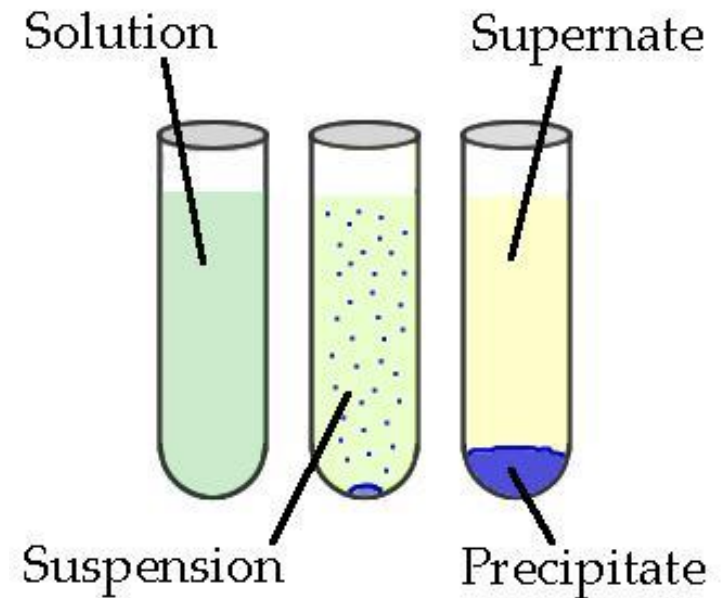
EXAMPLES USED IN FORMULATION SCIENCE

ACID	BASE	pKa (pH)
Phosphoric acid (H_3PO_4)	Monosodium phosphate (NaH_2PO_4)	2.12
Monosodium phosphate (NaH_2PO_4)	Disodium phosphate (Na_2HPO_4)	7.21
Disodium phosphate (Na_2HPO_4)	Trisodium phosphate (Na_3PO_4)	12.67
Citric acid	Monosodium citrate	3.15
Monosodium citrate	Disodium citrate	4.78
Disodium citrate	Trisodium citrate	6.4
Acetic acid (CH_3COOH)	Sodium acetate (CH_3COONa)	4.74
Carbonic acid (H_2CO_3)	Sodium bicarbonate (NaHCO_3)	6.4
Sodium bicarbonate (NaHCO_3)	Sodium carbonate (Na_2CO_3)	10.3



PRECIPITATION

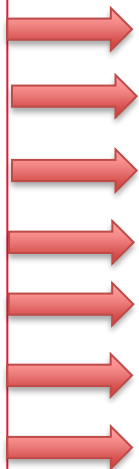
- Precipitation is the process whereby a solute (e.g. drug) dissolved in solvent loses affinity for solvent and reverts to its solid form, yielding a solid dispersed in a liquid (suspension).
- Precipitation will commonly cloud the solution
- It can be considered the reverse of dissolution
- Precipitated drug typically makes a drug solution go cloudy and results from a change in the solubility of one component



CAUSES OF PRECIPITATION

Causes of precipitation

- Solid state changes
- Temperature
- Solvent
- pH
- Incompatible species
- Chemical degradation
- Excessive addition



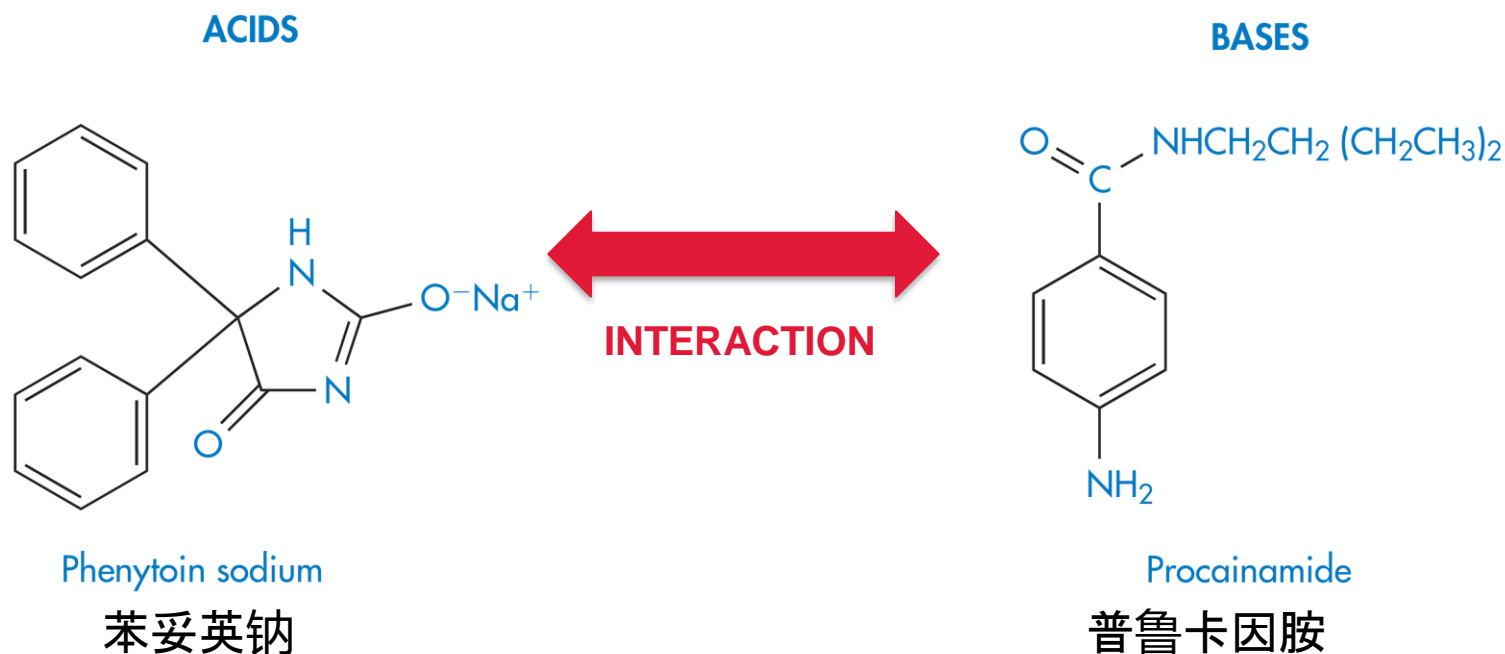
Example

- Slow polymorphic (多态的) changes
- Refrigeration
- Dilution of a cosolvent
- pH change on mixing/admin
- Admixing (混合) incompatibility
- Loss of hydrophilic group
- Preparation of concentrates



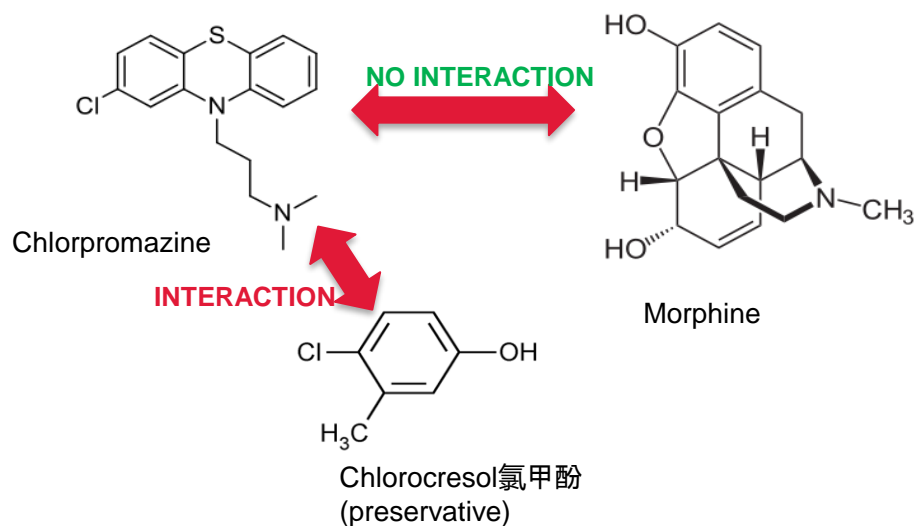
CATION AND ANION INTERACTIONS

- Mixture of a solvated cation and solvated anion may result in the formation of an insoluble precipitate
- E.g. Phenytoin sodium and procainamide



INTERACTIONS ARE NOT ALWAYS DRUG-DRUG

- Mixture of morphine 吗啡 and chlorpromazine 氯丙嗪 injections



对比项	氯丙嗪-氯甲酚	氯丙嗪-吗啡
氢键	羟基与氨基直接互补	羟基/胺基空间隔离或活性不足
π - π 堆积	平面芳香环有效堆叠	稠环结构阻碍平面匹配
极性匹配	疏水/极性区域互补	极性基团分布分散且刚性固定
构象柔韧性	侧链可调整适应结合	刚性骨架限制构象调整

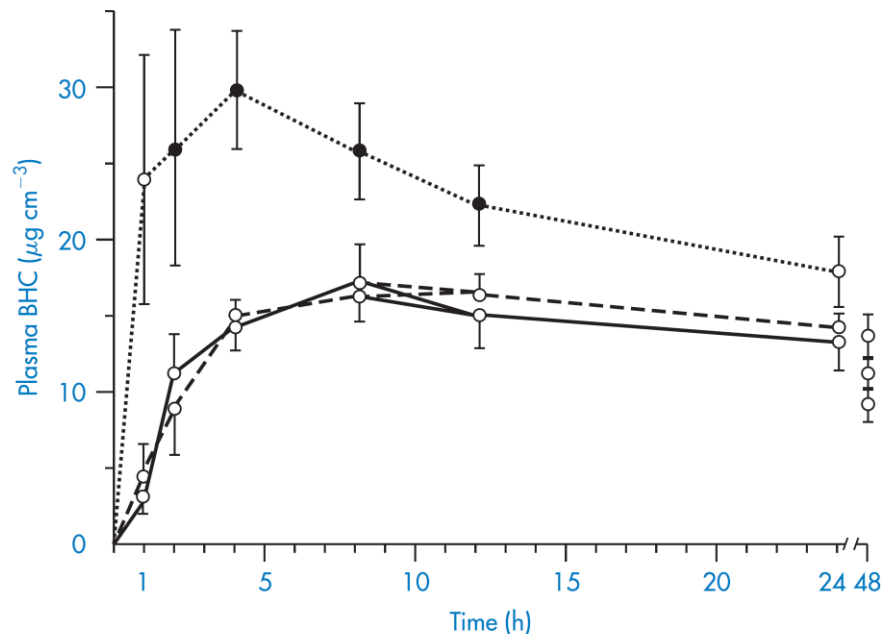
根本原因：氯甲酚的小分子平面结构和活性羟基使其易于与氯丙嗪的作用位点匹配，而吗啡的刚性多环体系和功能基团空间分布导致两者无法形成有效作用力。



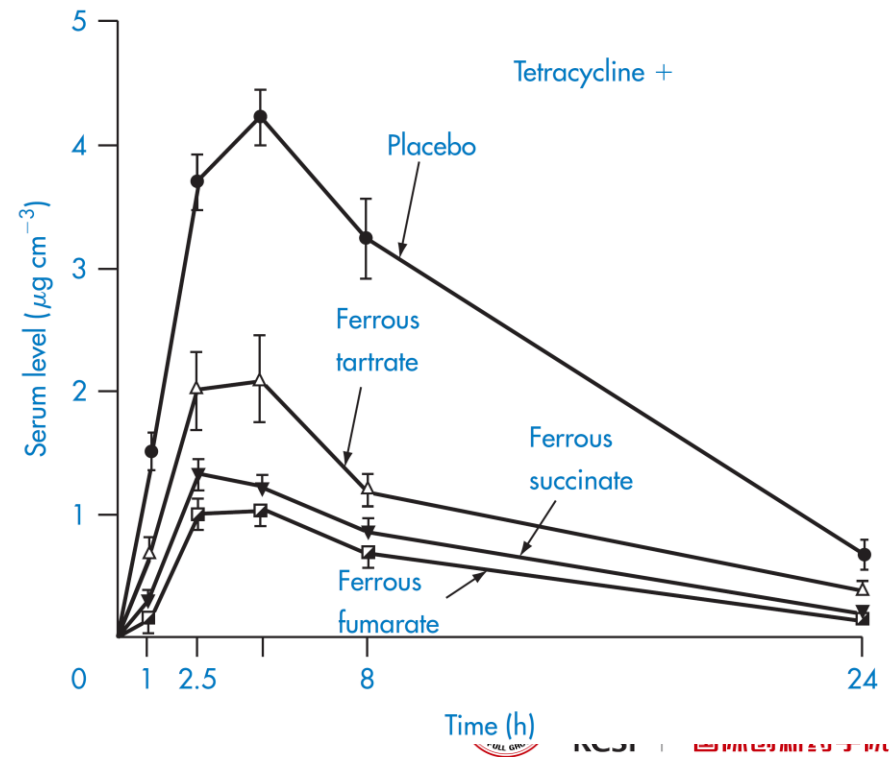
CHELATION

- **Chelation**: Relates to the interaction between a metal atom or ion and another species (ligand)

CHELATION INCREASED ABSORPTION

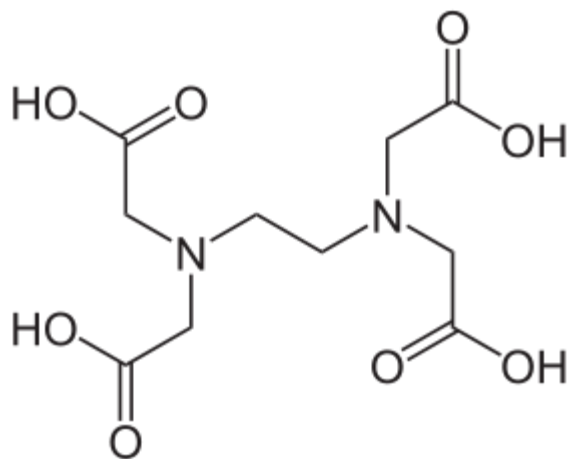


CHELATION DECREASED ABSORPTION

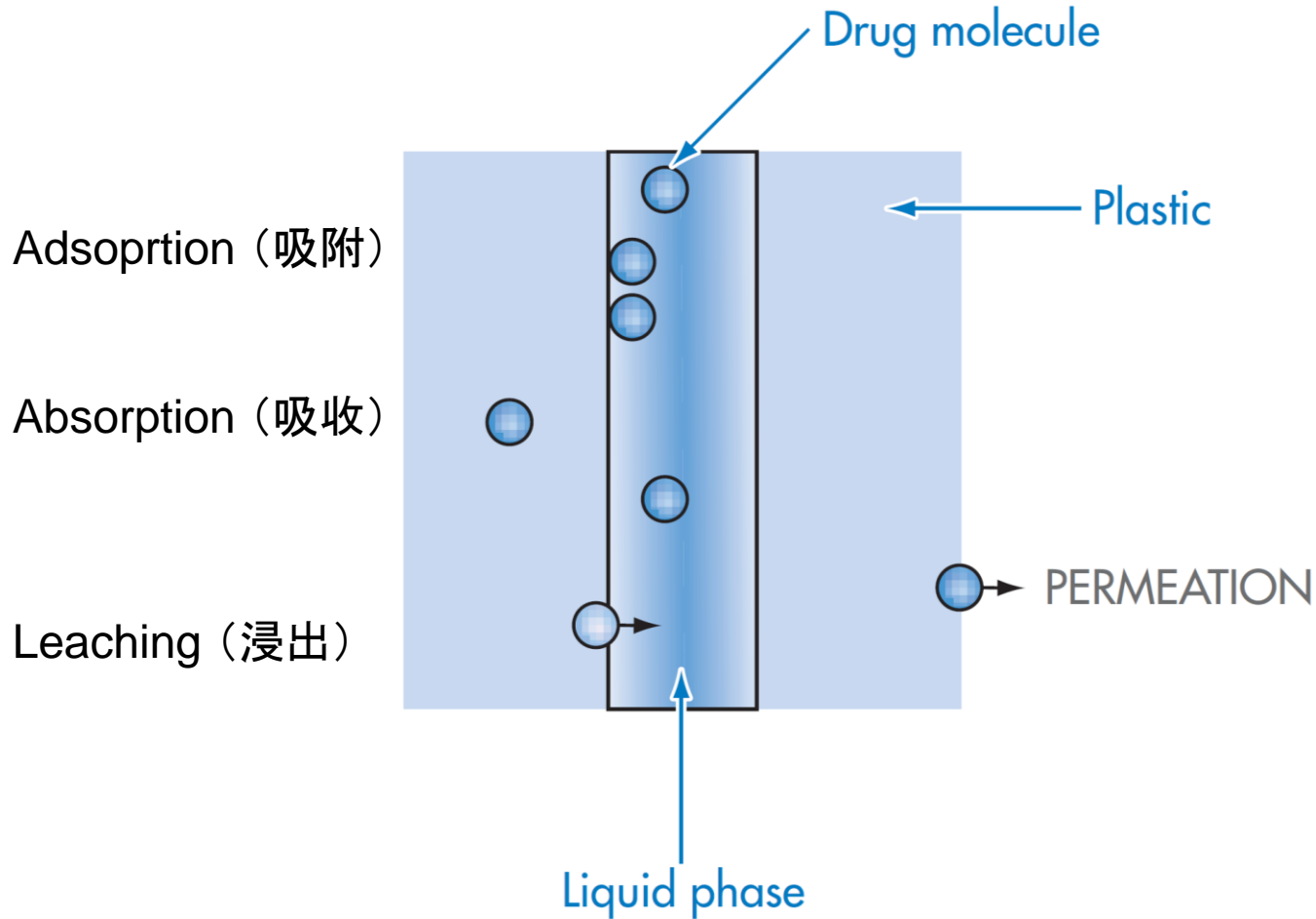


CHELATORS AS ANTIOXIDANTS

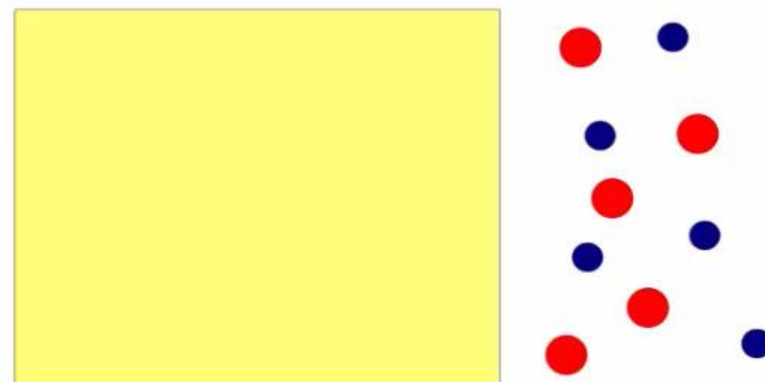
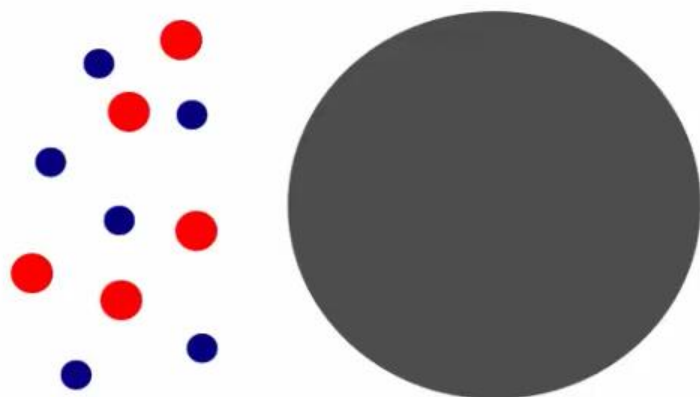
- Chelators are common pharmaceutical excipients used in pharmaceutical dosage forms and their ability to bind to drugs can alter the behaviour of that substance, whether in a dosage form or post administration
- EDTA is also used to chelate substances in cases of poisoning (e.g. lead 铅)



ADSORPTION, ABSORPTION AND LEACHING



ADSORPTION VS ABSORPTION



Adsorption	Absorption
The adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid to a surface .	A process in which atoms, molecules or ions enter some bulk phase (liquid or solid material).
Examples: activated carbon filters, chromatography	Examples: paper towels absorbing water, CO ₂ from air into NaOH

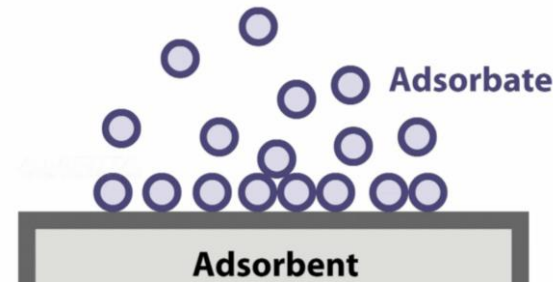
SOLUTIONS: ADSORPTION AT THE SOLID LIQUID INTERFACE

- **Interface**: Is the boundary between two phases
- **Absorption**: Is penetration into the bulk of a phase
- **Adsorption**: The process of accumulation at an interface. The tendency of materials to locate an interphase at a higher concentration than the bulk of a phase relates to interfacial phenomena

Types of Adsorption

(i) Physical Adsorption
(physisorption)

(ii) Chemical Adsorption
(Chemisorption)

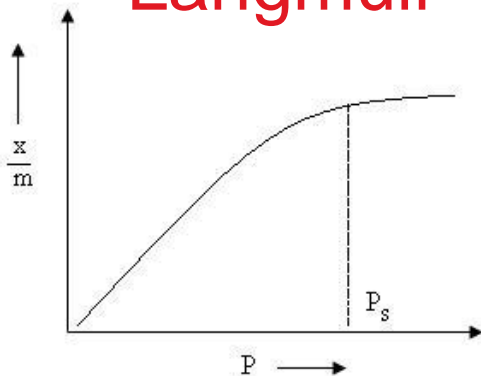


- 物理吸附: 由范德华力(分子间作用力)驱动, 无电子转移。
- 化学吸附: 通过化学键(共价键、离子键等)结合, 伴随电子重新分布或转移。

MODELLING ADSORPTION: ADSORPTION FROM SOLUTION COMMONLY FOLLOWS TYPE I ADSORPTION ISOTHERMS

- Two models of Type I (Langmuir and Freundlich models)

Langmuir



Suitable for monolayer; uniform surface

$$\frac{x}{m} = \frac{abC}{1 + bC}$$

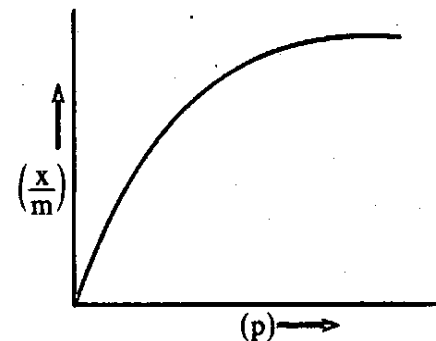
x/m : solute adsorbed/ weight of adsorbent

C : is the concentration of the solution at equilibrium

b : is a constant related to the enthalpy (焓) of adsorption

a : is related to the surface area

Freundlich



Suitable for multi-layer; heterogeneous surface

$$\frac{x}{m} = kC^{1/n}$$

x/m : solute adsorbed/ weight of adsorbent

k : Constant

C : Concentration

n : Constant



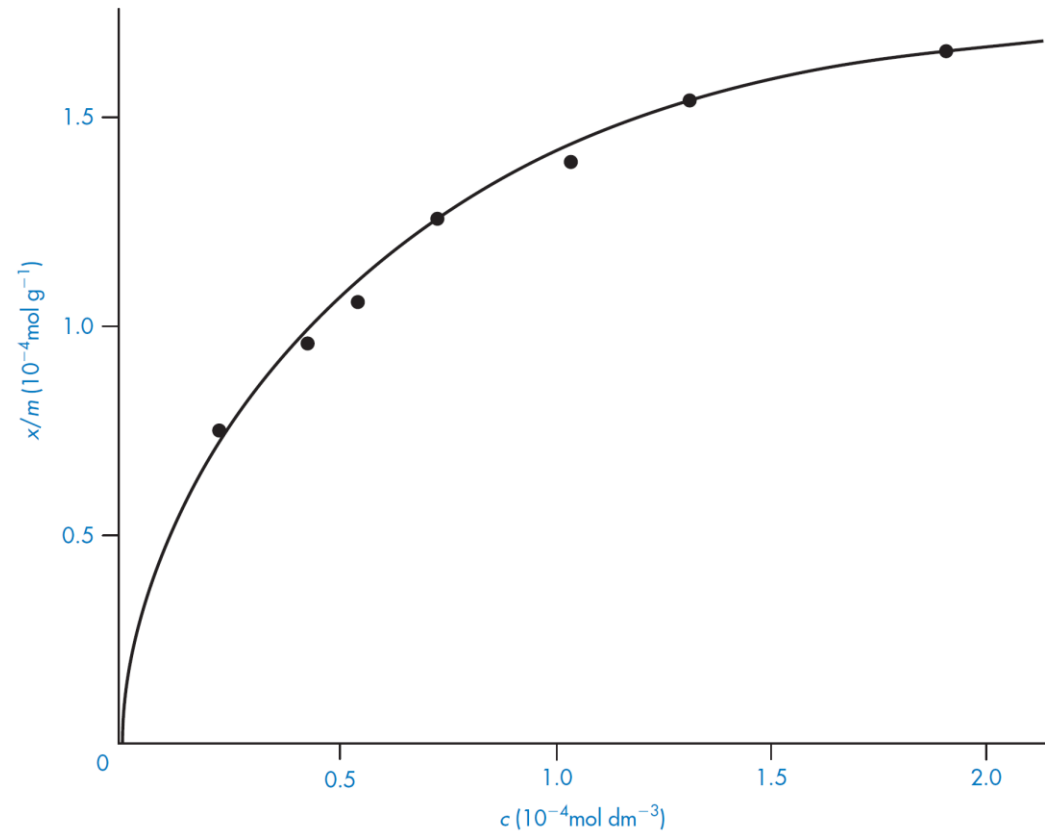
FACTORS AFFECTING ADSORPTION IN SOLUTIONS

- (1) Solute concentration
- (2) Temperature
- (3) pH
- (4) Solubility of the adsorbate
- (5) Nature of the adsorbent



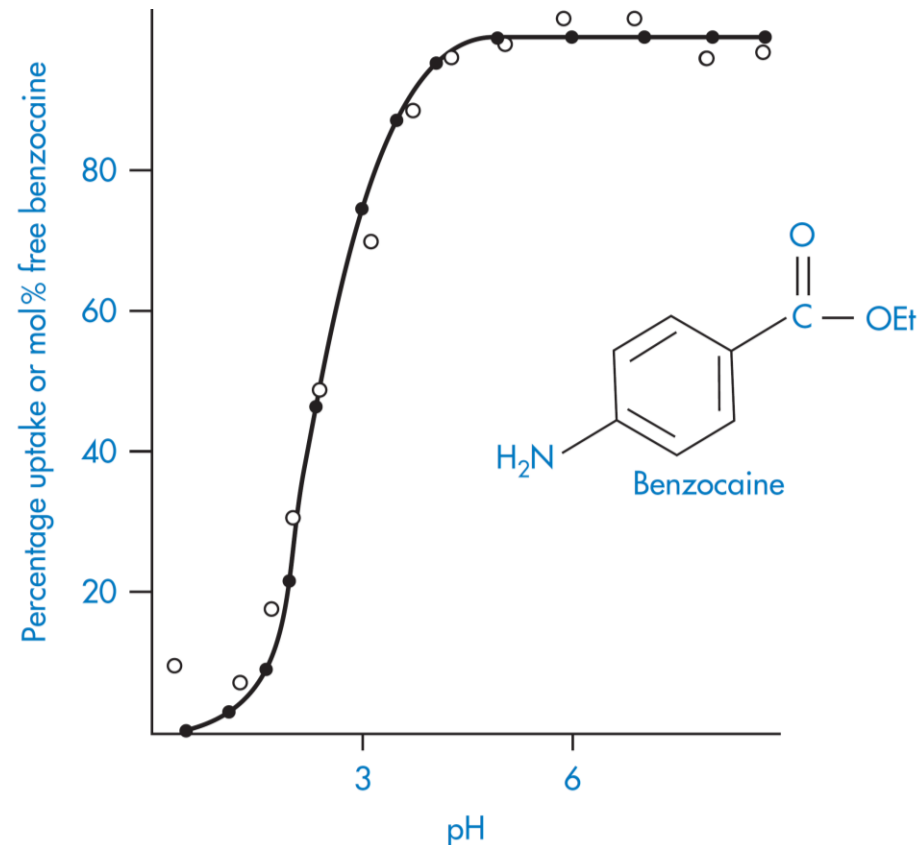
INFLUENCE OF CONCENTRATION ON ADSORPTION

- An increase in concentration of the solute will lead to an increase in the amount of adsorption.
- Langmuir and Freundlich isotherms



INFLUENCE OF PH ON ADSORPTION

- For simple solutes, adsorption increases when ionisation is suppressed. The extent of adsorption increases until all of the drug is unionised and the interface is saturated
- Acids max adsorption at low pH
- Bases max adsorption at high pH
- Amphoteric两性的: max adsorption at the isoelectric point 等电点



INFLUENCE OF SOLUBILITY ON ADSORPTION

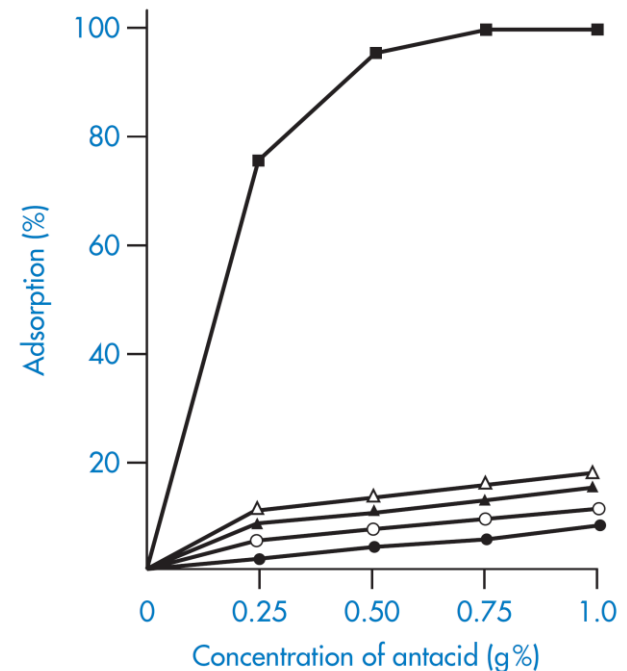
- In general, solubility is inversely proportional (反比例关系) to adsorption

High solubility indicates strong solute solvent bonds which must be broken for adsorption to occur



INFLUENCE OF THE ADSORBENT 吸附剂 ON ADSORPTION

- The adsorbent can have a profound effect on the rate and capacity for adsorption. Extent of adsorption is proportional to surface area (e.g. charcoal)
- Adsorbate and adsorbent interactions are highly complex especially when the adsorbent is charged (e.g. kaolin is cation and will therefore bind drug (e.g. anionic aspirin) in the ionised form)
- Adsorption of drug in the GI can reduce absorption as most adsorbents are not absorbed themselves.



INFLUENCE OF TEMPERATURE ON ADSORPTION

- Adsorption is usually an exothermic process, hence an increase in temperature will commonly result in a decrease in adsorption
 - Small changes in temperature have little effect on adsorption

INFLUENCE OF CHEMICAL PROPERTIES OF THE DRUG

- Drugs that are surface active (i.e. have surfactant properties) are likely to preferentially seek out interfaces having a more profound impact on the effective concentration



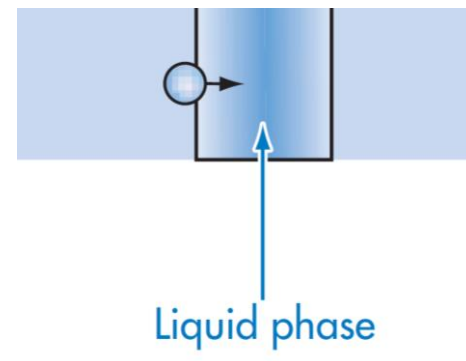
ADSORPTION IN FORMULATION SCIENCE

- Adsorption of toxins and poisons
- Adsorption of diazepam on to solid adsorbents minimises taste problems (taste masking)
- Adsorption can reduce the effective concentration of highly potent, lipophilic drugs reducing their efficacy (e.g. eye drops)
- Adsorption can lead to precipitation of protein drugs (e.g. insulin)
- Reduced efficacy of preservatives
- Adsorption to various types of plastics can be followed by absorption in to the bulk of the plastic and desorption
- Adsorption of materials to filters

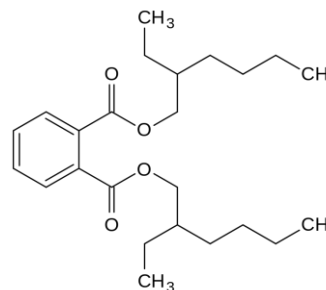


LEACHING

- **Leaching**: Is loss of materials from the packaging into the drug solution



- **Diethylhexylphthalate (DEHP)**: Is a lipid soluble plasticiser (substances that increase plasticity and fluidity of materials) used in PVC bags



- Solutions containing surfactants, cosolvents and oily vehicles leach DEHP out of the packaging and into solution
 - Requirement to use non-DEHP giving sets
 - Use of glass or polyethylene storage vessels

ABSORPTION: GLYCERYL TRINITRATE

- GTN三硝酸甘油酯 is a volatile drug that partitions into the walls of plastic containers.
- Significant losses (up to 50%) have been noted through plastic giving sets requiring in the use of high doses.
- LogP Hexane:water has been used to determine the absorption of drugs into plastic materials with some degree of correlation



ADSORPTION AND ABSORPTION

COMPOUND	EXTENT OF ADSORPTION AT EQUILIBRIUM	Penetration index (LogP_{APP})	LogP (Hexane water)
DIAZEPAM	90	1.9	0.9
Nitrazepam	47	0.9	-0.1
Pentobarbital	0	0	-1.3

Properties of drugs in absorption and adsorption

- Lipophilic drugs and proteins prone to binding to plastics
- Polypropylene and polyethylene containing little or no plasticiser and are less likely to adsorb drug
- Proteins bind plastics and glass and this exposes hydrophobic moieties resulting in aggregation and destabilisation



ADSORPTION IN SOLUTION BOTTLES

Material	Leaching	Leaching extent	Adsorption extent	Extent permeable water	Extent permeable O ₂
Glass, borosilicate	Alkali (metal oxides)	1	2	0	0
Glass, soda lime	Metal oxides	5	2	0	0
High density polyethylene	antioxidants	1	2	3	3
Low density polyethylene	Plasticizers, antioxidants	2	2	5	5
Polyvinyl chloride	Plasticizers, stabilizers	4	2	5	2
Polypropylene	Antioxidants, lubricants	2	1	5	3
Rubber, natural	Metal salts, lubricants	5	3	3	3
Rubber, butyl	Metal salts, lubricants	3	2	1	1
Rubber, silicon	Minimal	2	1	5	5



RHEOLOGY

The study of *deformation* and *flow* of matter

It addresses the viscosity characteristics of solution and colloidal systems. The flow of simple liquids can be described by viscosity, an expression of the resistance to flow.

Liquids and solutions for which the flow characteristics can be adequately described by viscosity are called **Newtonian fluids**, and they are said to exhibit Newtonian flow characteristics. However, the flow of complex dispersions cannot be adequately described by viscosity. These fluids are termed **non-Newtonian**, and they are said to exhibit non-Newtonian flow characteristics.



COEFFICIENT OF VISCOSITY

Newton was the first to study flow properties of liquids in a quantitative way. He recognized that the higher the viscosity of a liquid, the greater is the force per unit area (shearing stress) required to produce a certain rate of shear.

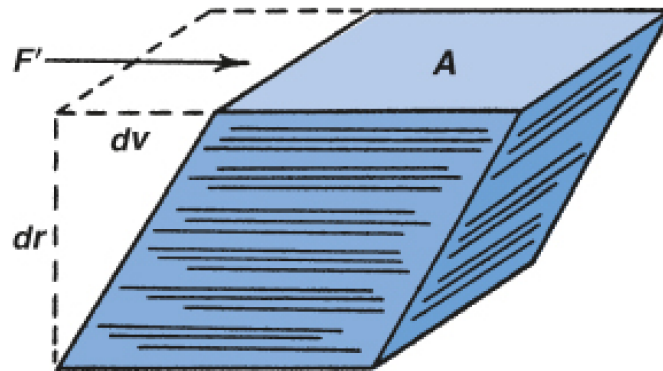


FIG. 16-1 Representation of the shearing force required to produce a definite velocity gradient between the parallel planes of a block of material.

$$\frac{F'}{A} = \eta \frac{dv}{dr} \quad (16-1)$$

where η is the *coefficient of viscosity*, usually referred to simply as *viscosity*.

NEWTON'S LAW OF FLOW

Newton's law of flow states that the application of stress on a liquid leads to flow in the direct proportion to the amount of stress applied.

$$t = \eta \bullet D$$

The constant that relates the flow of a liquid to the applied stress is called **viscosity, η** .

D is the rate of flow.

t is the applied stress.

TABLE 16-1 **Absolute Viscosity of Some Newtonian Liquids at 20°C**

Liquid	Viscosity (cp)
Castor oil	1,000
Chloroform	0.563
Ethyl alcohol	1.19
Glycerin, 93%	400
Olive oil	100
Water	1.0019



REPRESENTATIVE FLOW CURVES

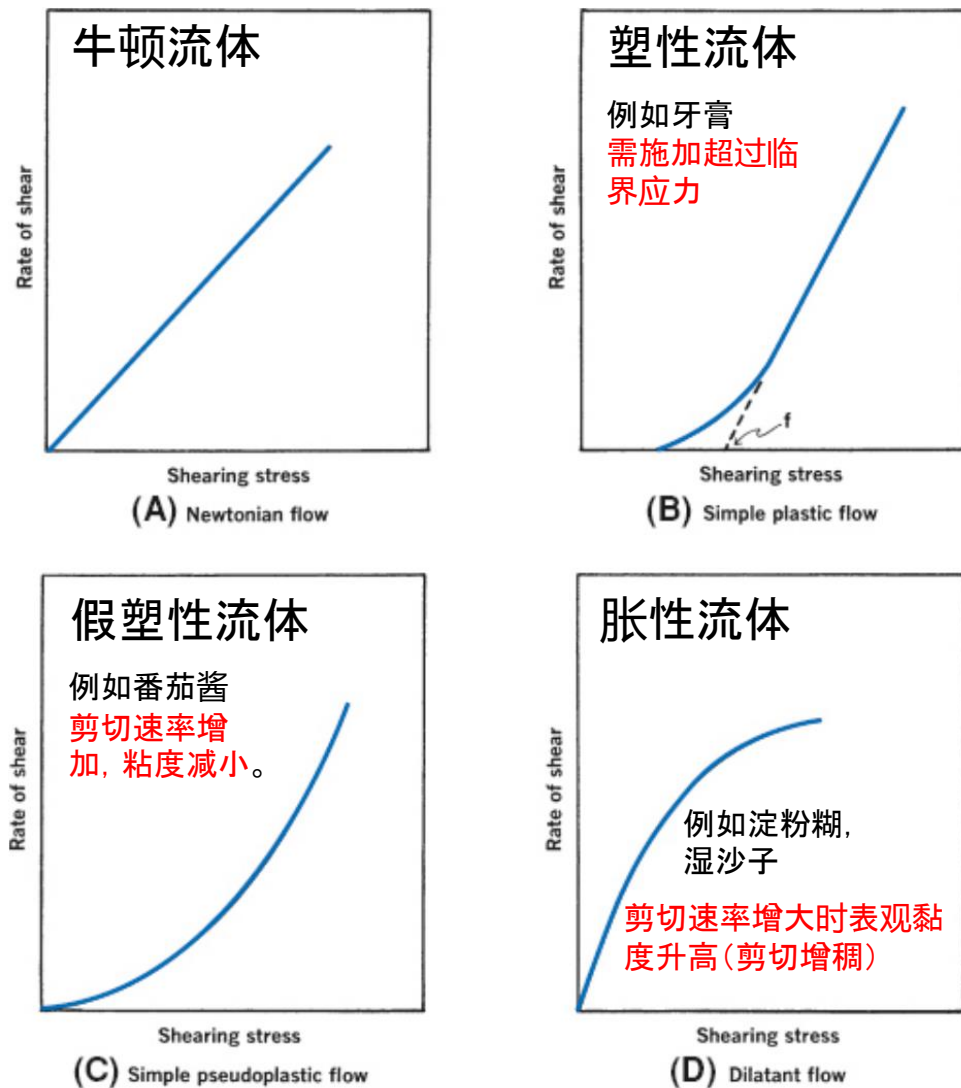


FIG. 16-2 Representative flow curves for various materials.

NON-NEWTONIAN FLUIDS

Fluids that obey Newton's law of flow are referred to as Newtonian fluids, and fluids that **deviate from the linear stress–flow proportionality** expressed by the Newton's law are called **non-Newtonian fluids**.

$$F = \frac{F'}{A} = \eta \frac{dv}{dr}$$

Force per unit area (F'/A) required to bring about flow is called the shearing stress (F).

dv/dr is the rate of shear representing the velocity of fluid movement per unit distance from the plane of shear stress.

The units of F'/A are dynes per cm² or Pascal. The units of dv/dr are (cm/sec)/cm = sec⁻¹. Thus, the Standard International (SI) unit of viscosity is Pascal*second (Pa*s). The more commonly used unit of viscosity is dyne*second/cm², which is named Poise (P).



NON-NEWTONIAN FLUIDS

RHEOLOGY

The study of *deformation* and *flow* of matter

Stress (τ , S , $\underline{\sigma}$, F): Force applied per unit area (Pa).

Stress: system of forces applied to matter in either elongation, compression, bending, twisting or shearing modes leading to a strain

Strain (γ): deformation under stress (no units)

Strain: change in size or shape In fluids shear rate ($\dot{\gamma}$) with units of per second (s^{-1})

Viscosity refers to the resistance to flow or movement of a fluid (mPa s)

OF SIGNIFICANT IMPORTANCE IN
DISPERSED SYSTEM (E.G. GELS)



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EXAMPLE SHEAR RATES FOR STANDARD OPERATIONS

OPERATION	SHEAR (S ⁻¹)
Pouring liquid from a bottle	50
Stirring	10-1000
Injecting via a syringe	4000
Dispensing a nasal spray	20,000
Industrial processing (milling, spray coating and spray drying)	10 ⁵ -10 ⁶



VISCOSITY VALUES FOR SELECTED SOLVENTS AND SOLUTIONS

SUBSTANCE	VISCOSITY (mPa.s)
Water (pure)	0.89
Water (@ 50°C)	0.55
Ethanol (absolute)	1.2
Ethanol (40%w/w)	2.9
Glycerin	1500
Simple syrup (85% sucrose)	125
Corn syrup	1381
Mineral oil	110-230
Olive oil	100
Propylene glycol	58.1
Tomato ketchup	50,000 – 70,000



VISCOSITY OF SOLUTIONS

- Highly concentrated solutions have high viscosity values, particularly solutions of solid or viscous liquid in water.

- POURABILITY
- SPREADABILITY
- SYRINGABILITY
- CONTROLLED RELEASE
- DISSOLUTION
- PROCESSABILITY



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