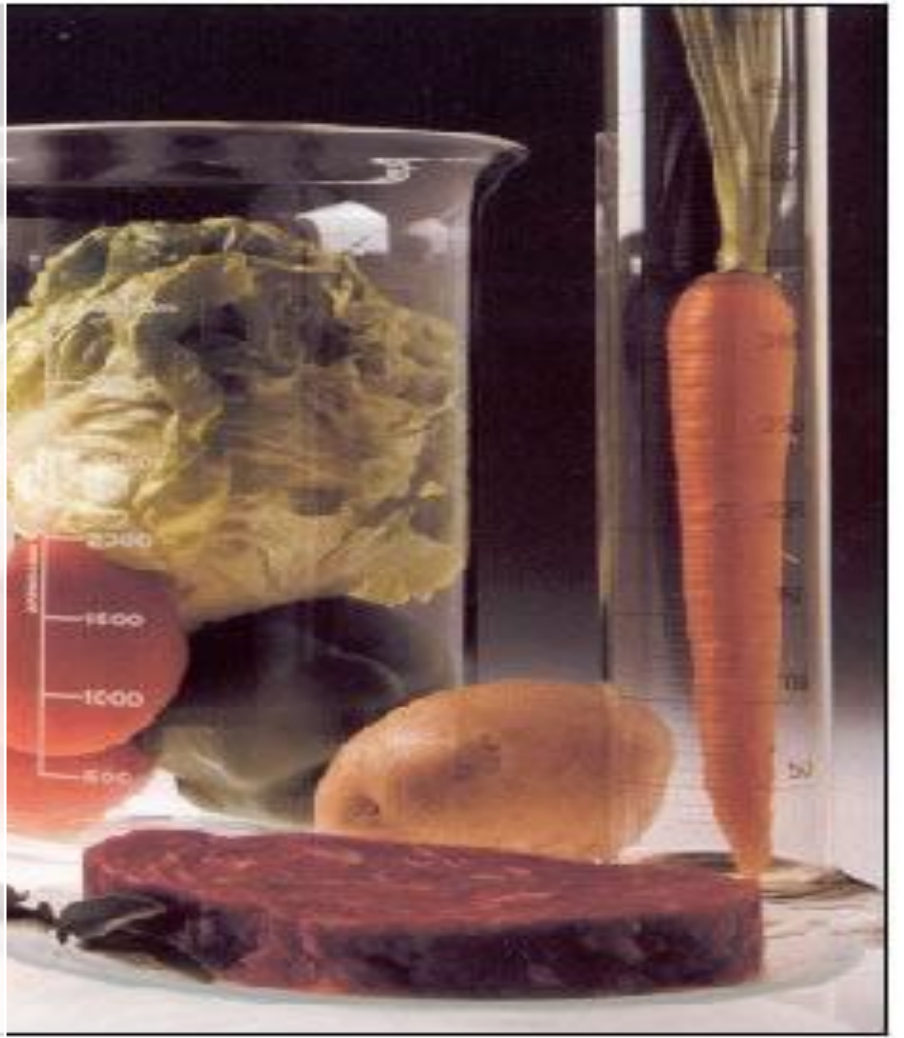


Food Chemistry

Option F Summary

2011



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F.1 ◊ FOOD GROUPS

F.1.1 ◊ FOODS AND NUTRIENTS

- **Food:** any natural/artificial material intended for human consumption, composed of chemicals which provide fuel/energy for bodily functions and building blocks for growth/regeneration
- **Nutrient:** component of food used by body to provide energy, growth/repair of tissues
 - Lipids
 - Carbohydrates
 - Proteins
 - Vitamins
 - Minerals
 - Water
- **Malnourishment:** lack of nutrient quantities in diet OR lack of **balance** in nutrient proportions in diet

F.1.2 ◊ LIPIDS, CARBS, AND PROTEINS

- **Lipids:** fats + oils → esters composed of **glycerol** (propan-1,2,3-triol) + **fatty acid** (carboxyl) chains (1, 2, or 3) → source of energy + cell membranes
 - **Saturated fatty acid** have only sp^3 C hybridization (no double bonds) → pack together → solid (fats)
 - **(poly)unsaturated** have 1 or more sp^2 -hybrid C (1 or more double bonds) → prevents packing → liquid (oils)
- **Carbohydrates:** CH_2O → sugars and polymers, e.g. starches, cellulose → energy source, structural material, energy storage
 - **Monosaccharide:** $(CH_2O)_n$ $n > 2$ → simple sugars w/ 1 carbonyl (C=O) and at least 2 hydroxyl (OH)
 - **Disaccharide:** formed via condensation of 2 monosaccharides, e.g. glucose + glucose → maltose, g + fructose → sucrose
- **Proteins:** polymers of amino acids → C, H, O, N, many have P, S
 - Structural material
 - Storage/transport
 - Hormones (signals)
 - Energy/locomotion
 - Immunity/antibodies
 - Enzymes/catalysts

F.2 ◊ FATS AND OILS

F.2.1 ◊ SATURATED AND UNSATURATED

- **Fat** triglyceride in solid form at room temp., usually from animal source; almost completely **saturated** (lard, butter)
- **Oil:** triglyceride in liquid form at room temp., usually from plant sources; usually **unsaturated** (olive oil, corn oil, cod oil)
- Usually **mixture** of chain lengths / degrees of saturation → proportions determine lipid properties, e.g. **crystallinity:**
 - Mean hydrocarbon chain **length** → longer = more VDW = higher MP
 - Degree of **unsaturation** → causes “kinks”, separating molecules → lower VDW strength = lower MP
 - **Cis or trans** about double bonds → **cis** creates much more of a “bend” than trans (see above pt.) = lower MP

F.2.3 ◊ STRUCTURE AND STABILITY

- **Saturated** have sp^3 → very stable configuration compared to pi-bonds in sp^2 → **unsaturated** more reactive/keep less well
 - Main problem → **auto-oxidation:** reaction of C=C with O_2 , esp. in presence of light (**photo-oxidation**) → causes discoloration (i.e. of margarine)
 - **Unsaturated** also prone to **hydrogenation, hydrolysis**, and enzymatic degradation by microbes

F.2.4 ◊ HYDROGENATION

- **Unsaturated** oils can be **hydrogenated** w/ H_2 @ high P + T (200°C) → need **catalysts** for industrial feasibility (e.g. Ni)
 - Can produce lipids that are **more saturated** or even **completely saturated**

Advantages:

- Product is semi-solid or solid instead of liquid → easier for some cooking techniques
- Product is more stable → oxidation rate decreased by sp^3 → takes longer to spoil
- Texture can be controlled, i.e. hardness + plasticity

Disadvantages:

- Mono/polyunsaturated are **healthier**, esp. for heart → do **not** cause **atherosclerosis** (clogging)
- Partial/incomplete hydrogenation causes **trans-fats** (not naturally occurring) → cannot be metabolised well by body
 - Accumulate in fatty tissues and blood vessels → heart diseases, obesity, stroke, etc.
 - Cause increase in LDL (low-density lipoprotein) cholesterol (mainly fat) → **atherosclerosis** → heart disease

F.3 ◊ SHELF LIFE

F.3.1 ◊ FACTORS AFFECTING SHELF LIFE

- **Shelf life:** length of time a product can be stored without gradual degradation of flavour, smell, texture, appearance, or microorganism growth, to the point of being **unfit** for safe consumption. Based on:
 1. **Change in H₂O content from air contact:** dehydration of moist foods causes undesirable texture; air exposure causes increased **rate of oxidation** and decrease in nutrient value, discoloration, rancidity
 - Dry foods that absorb H₂O become more prone to **microbial degradation**
 2. **Chemical reaction:** can produce pH changes (souring) or other undesirable flavours, colour changes, nutritional decrease
 - O₂ presence increases rate of **oxidative degradation**
 3. **Light:** provides energy for photochemical reactions (rancidity, flavour change), colour fading, nutrient (vitamin) oxidation
 - Also encourages growth of some microbes by creating warmer environment
 4. **Temperature:** increases rate of chemical reactions → faster food degradation
- **Water** determines texture, softness, “juiciness” (depends on **how** water molecules are present)
 - H₂O may be bonded to carbs or protein **polar groups** OR **free** but linked (H-bond) w/ proteins and polysaccharides
 - Change to forces of attraction (IMFAs) holding carb/protein chains together influences **total water content**
 - I.e. pH or temp. change → disrupts IMFAs → changes H₂O content → affects texture, softness, juiciness, etc.

F.3.2 ◊ EXTENDING SHELF LIFE

- Involves reducing rate of fat rancidification
 1. **Packaging:**
 - Opaque packaging / coloured bottles reduce photo-oxidation
 - Gas-impermeable wrapping reduces exposure to O₂ and H₂O vapour; free space in container also minimized
 - Vacuum packaging / filling container w/ **inert gas** → e.g. potato chips packed in bags w/ N₂
 2. **Storage:**
 - Refrigeration → reduces rate of degradation reactions (e.g. dairy)
 - Dark storage (oils + fats) → reduced photo-oxidation (which is less affected by temp.)
 - Reducing H₂O c (**drying** or **smoking**) and storing w/o moisture → reduces **hydrolytic rancidity** / microbe growth
 3. **Additives:**
 - **Salting** (high [salt]) and **preserves** (high [sugar]) create hypertonic environments → food is dehydrated + kill microbes → reduces hydrolytic rancidity
 - **SO₂** and **Na₂SO₃** (fruits) and **sodium/potassium nitrates/nitrites** (**curing** meats) → reducing agents; prevent oxidative reactions (e.g. browning if stored too long)
 4. **Anti-microbial:**
 - **Pickling** → vinegar creates acidic environment hostile to microbe growth; other organic acids/salts added to discourage mould/fungus/bacterial growth
 - E.g. benzoic acid – NaBenzoate to fruit juices; Propanoic acid + NaPropanoate + CaPropanoate to bread/cheese
 - **Fermentation:** produces ethanol (limits bacterial growth), e.g. wine, beers, distilled spirits (higher % alcohol)

F.3.3 ◊ FAT RANCIDITY

- **Rancidity:** food degradation → development of unpleasant smells in fats and oils, often w/ changes in texture/appearance
 - a) **Hydrolytic rancidity** → ester bond (glycerol-f. acid bond) broken w/ **lipase**, heat, moisture → glycerol + **free** f. acids
 - Smaller (4-8 C) fatty acids (Butanoic, hexanoic, octanoic) → **unpleasant** smell/taste, e.g. in milk, butter
 - Longer chains **less volatile** → smell/taste less noticeable BUT free f. acids (stearic, oleic) → fatty/soapy feel
 - Hydrolysis rate **increases w/ enzymes** (lipase) produced by microorganisms on food or **deep-frying** (hydrolytic reaction btwn cooking oil and food moisture)
 - b) **Oxidative rancidity** → “auto-oxidation” → C=C (unsaturated lipids) with **atmospheric** O₂; less in saturated lipids
 - Complex **free-radical** reactions → variety of products w/ unpleasant odour/taste
 - **Light** (esp. UV) leads to **photo-oxidation**, also creates free-radicals
 - **Enzymes** (e.g. microorganisms) – catalyze oxidative rancidity

F.3.4 ♦ FREE-RADICAL CHAIN REACTION

1. **Initiation:** unsaturated lipids exposed to light (UV – photo-oxidation → high E_A) → **homolytic fission** of C-H bond
 - May also occur from decomposition of **hydroperoxides** (product of rxn) catalyzed by transition metal ions
2. **Propagation:** HC free radicals + O_2 → peroxide radicals → abstract H from other molecules → HC radicals re-formed
 - Continue until termination reaction **destroys** free radicals → this is rare (1 radical must meet another directly) → 1 step can produce high [hydroperoxides]
3. **Termination:** removal of free radicals from system by radical-radical reaction; 3 combinations for this step
 - Hydroperoxides (ROOH) are **very reactive** → gradually converted to **aldehydes / ketones** (bad smell)
 - Aldehydes oxidized to long chain fatty acids → bad taste/smell (“**rancidity**” / “spoiling”)

F.3.7 ♦ ANTIOXIDANTS

- **Antioxidant:** substance added to food to increase shelf life → delays onset of oxidative degradation (interferes w/ auto-oxidation). Many react w/ oxygen radicals → “nullify” them (prevent them from degrading food). **Natural antioxidants:**
 - **Vitamin C** (ascorbic acid) → citrus fruits, green veggies
 - **Vitamin E** (a-tocopherol) → nuts, seeds, soya beans, whole grains, some veggie oils (canola)
 - **B-carotene** → carrots, broccoli, tomatoes, peaches
 - **Selenium** → fish, shellfish, meat, eggs, grains → vital in trace quantities, toxic in high [].
 - **Synthetic antioxidants** → BHA, BHT, PG, THBP, TBHQ → all have **phenolic** structures (OH attached to benzene) → not found in natural antioxidants → **may** have harmful side effects, but no concrete proof
 - **Traditional antioxidants** → green tea, turmeric, oregano, blueberries, cranberries, dark chocolate, red wine
 - Claimed to reduce LDL, blood sugar, BP, cancer cell development → not yet proven
1. **Free radical quenchers:** reacts w/ free radicals to produce less reactive substances (less reactive radicals)
 - E.g. vitamin E; BHA, TBHQ, BHT
 2. **Chelating agents:** form very stable complex ions w. transition metals (react w/ hydroperoxides to produce free radicals) → reduce frequency of these reactions
 - E.g. rosemary, tea, mustard, EDTA (artificial)
 3. **Reducing agents:** react w/ both O in food and hydroperoxides (initially from auto-oxidation) → “deactivated”
 - E.g. vitamin C, carotenoids (B-carotene); also artificial preservatives SO_2 , sulfites, nitrites

Advantages:

- Natural vitamins (C, E, carotenoids) reduce cancer/heart disease risk → inhibit free radicals
- Vitamin C is vital in hormone production + collagen; B-carotene as margarine additive (colour) and vitamin A precursor

Disadvantages:

- Consumers perceive synth antioxidants as “less safe” (not naturally-occurring)
- Natural antioxidants add colour and aftertaste; less effective at slowing rancidification than synth
- Synth antioxidants are “food additives” → must be regulated by policies/legislation for safety
- Policies on labelling / safe additive use can be difficult to monitor, esp. in developing countries (exporting countries)

F.4 ♦ COLOUR

F.4.1 ♦ DYES AND PIGMENTS

- **Pigments** : colouring materials **naturally** present in foods
- **Dyes:** synthetic or natural (from different source) coloured compounds added to **enhance appearance** of processed food
 - Usually H_2O -soluble → thoroughly tested for safety
- **Colour** produced when certain frequencies of light are **absorbed** while **reflecting** others → stimulate eye retina → i.e. **Colour of food** depends on **reflected** light

F.4.2 ♦ ANTHOCYANINS

- Most common pigments → **reds, pink, purple, and blues** (berries, beets, red cabbage, many flowers)
- All have similar **3-ring** $C_6C_3C_6$ structure w/ conjugated **double bonds** → vary in #/position of OH / alkoxy side chains
 - Often found bonded to **sugar** side chains → changes their colouring
- Structure dependent on **pH** → both in acid-base rxns and effect of pH on ease of hydration → colour of anthocyanin foods varies w/ cooking or when mixed w/ **acid/alkali** ingredients
- Form complex ions w/ metal ions (Fe^{3+} / Al^{3+}) → prolonged contact (i.e. w/ kitchen utensils) causes colour change
- @ **high temp** → decomposition → “browning” during cooking
- Exists in **4** related structural forms in **equilibrium** → position depends on pH, temperature, etc. → act as acid/base ind.
 - A and B are most brightly coloured → stable at low temperatures (A at low pH) → absorption spectrum **varies** w/ pH

- **Low pH** → flavylum cation (AH⁺) → **red**
- **Neutral pH** → enough [OH] for → flavylum hydrolysed → carbinol pseudobase (B) + chalcone (C) → **colourless**
- **High pH** → flavylum cation converted → quinoidal base (A) → shifts all equilibria to A → **blue**
- **Flavanones**: closely related to anthocyanins; found in many berries and grapes

F.4.3 ◊ CAROTENOIDS

- Widely found in all living things → **yellow, orange, reds** → algae, carrots, bananas, tomatoes, saffron
 - Low levels in grass, but eaten by cows and concentrated in milk fats → give butter yellow colour
- Nutritional value → converted into **vitamin A** and are effective antioxidants
- Essential structural feature: **long hydrocarbon chain** (sometimes w/ attached methyls, or rings at end)
- Some have **hydroxyl** groups near chain end / on ring; BUT **carotenes** have hydrocarbon structure instead (e.g. on ring)
- Relatively **stable** in most food-processing stages (pH 2-7) → do not lose colour easily
 - **Excess heating** (>50°C) causes some discolouration and changes **trans** double bonds to **cis**
 - Like (poly)unsaturated lipids, carotenoids vulnerable to **oxidative degradation** (light-accelerated → ROOH radicals)
 - Oxidative degradation also catalyzed by transition metal ions → **if oxidized**/decolourized → can't become vitamin A
- **Astaxanthins**: red pigment related to carotenoids → found naturally bonded to proteins (which modify absorbency frequencies → blue-green colour in lobsters and crabs)
 - **High temp.** disrupts bonds w/ protein so **blue-green** → **red** during cooking
 - Like carotenoids, acts as antioxidant (shrimps/prawn shells are "healthy") → also causes pinkness of salmon meat

F.4.4 ◊ CHLOROPHYLLS

- **Green**-coloured pigments → catalyse photosynthetic processes in green plants/vegetables
 - **Chlorophyll a** → Mg²⁺ @ ring centre; has **methyl** group; **Chlorophyll b** has **aldehyde**
- **Cooking** → plant cells break down → releases acids (decrease pH)
 - Chlorophylls **stable** in neutral and alkaline; in **acidic** → H⁺ displaces Mg²⁺ into solution → **olive-brown** pheophytin
 - These changes also make pigment less stable in **light** → **photodegradation**

F.4.5 ◊ HEMES

- **Red** pigment in erythrocytes of higher animals → similar structure to chlorophyll w/ **Fe²⁺** instead of Mg²⁺
- **chlorophylls AND hemes** → planar ring systems w/ metal ion bonded to 4 N ligands → "**porphyrin**" ring
- **Muscles** → heme associated w/ **myoglobin** (quaternary protein) → **purple-red**
 - Binds easily to O₂ (oxygen transporter) → colour change → **bright red**
 - **Auto-oxidation** → much slower rxn w/ O₂ causes Fe²⁺ → Fe³⁺ → forms **metmyoglobin (brownish-red)**
 - Colour of meat can be preserved by storing in **O₂-free** environment, **vacuum-packing**, packing in **inert gas** (CO₂), w/ polymers of **low gas permeability**

F.4.6 ◊ PIGMENT STRUCTURE AND COLOUR

- **Delocalised π-bonding** → allows compounds to absorb/reflect light in visible spectrum → **colour**
 - Greater delocalisation → bonding and anti-bonding π-orbitals **closer in energy** → region in which **photons** excite e⁻ from one to another shifts from **UV** (benzene) → **visible**
- **Conjugated** double bonds (alternating single/double, i.e. resonance) → **extensive** delocalisation
 - In **anthocyanins** → delocalisation extends over all three rings, unless **sp³ C exist** (break π-delocalisation, e.g. carbinol)
 - In **carotenoids** → rings themselves not fully delocalised BUT delocalised system spreads from ring sections close to chain → along entire HC chains
 - In **chlorophyll + heme** → delocalisation of ring surrounding metal ion extends **slightly** into side chains
- **Anthocyanins** → many OH attached to ring → H-bond w/ H₂O → water-soluble
- **Carotenoids** → long hydrophobic HC chain, OH on chain not enough to overcome long hydrophobes → lipid-soluble

F.4.7 ◊ SAFETY ISSUES WITH SYNTHETIC COLOURANTS

- If synthetic dye is **biologically active** → health threat
 - NO international standards (banned in one country, legal in another) → difficulties for int'l trade
 - Synthetic dyes like **malachite green** and **sudan red** → found in imported food, even though banned in many countries
- **Acute** (short term) toxicity is **easy to test for** BUT **chronic** effects are difficult to prove (especially w/ carcinogens)

F.4.8 ◊ NON-ENZYMATIC BROWNING AND CARAMELIZATION

- Cooking foods causes browning (often used as indicator for sufficient cooking) → colour change is combo of **2 processes**:
 1. **Maillard reactions**: cause smell + colour change of common cooking processes (grilling meat, toasting bread, malting barley, making fudge, self-tanning) → **condensation reactions** with proteins and sugars
 - Aldehyde group in **reducing sugars** (glucose, lactose) reacts w/ **amino group** of a. acid or on side chains of peptides
 - | Reducing sugar + amino acid → initial condensation product |
 - Initial products polymerise → brown pigments (**melanoidins**)
 - Great variety of reactants = great variety of products (>1000 identified)
 - **Polymeric products** give **golden-brown** colour; **lower-molar-mass** products cause smell/flavour change
 - Usually occur > 140°C; rate varies w/ amino acids involved → cysteine is least reactive, lysine is VERY reactive → milk (high [lysine]) browns quickly (fudge) → e.g. heating sugar + cream to make toffees, caramels, fudges
 2. **Caramelisation**: foods w/ high [carb] heated and dehydrate
 - Initially, polymerization (variety of products causing brown colour); if continued →
 - $C_{(s)}$ production and food burns, i.e. $C_n(H_2O)_n \rightarrow nC + nH_2O$
 - Rate varies w/ involved sugar (fructose is easiest); **extreme pH** promotes caramelisation
 - Maillard reactions **require proteins** (a. acids) → browning of foods w/o proteins (toffee from sugar, crème brûlée and other baked-egg dishes) are caused by **caramelisation** → also produces volatile aromas (caramel)

F.5 ◊ GENETICALLY MODIFIED FOODS

F.5.1 ◊ PROS AND CONS

- Foods made from artificial modification of DNA sequence of micro-organisms, plants, and animals
- Advantages:**
- **Pest & disease resistance**: increases yield and health of many plants/animals; reduces need for chemicals/vaccines
 - Lowers treatment costs & harmful **toxins in environment/food residues**; can improve taste/quality
 - “Bio”-products (herbicides, etc.) → natural, friendly alternatives → soil, water, H₂O conservation, waste management
 - E.g. potatoes resistant to fungal infection; bananas resistant to nematodes
 - **Improves quality & range**: many crops geographically limited (specific growth conditions req'd)
 - GM enables production of varieties that can grow in wide climate range, produce bigger yield, and mature faster
 - E.g. high-yield rice enriched w/ vitamin A, and maize, that can grow in low-rainfall areas
 - **Production of medicinal/novel products**: GM used to enable plants/animals to produce what they normally wouldn't
 - Can produce **biologically-active** molecules for use as medicines
 - E.g. GM hens lay eggs w/ human interferon; cows give milk w/ omega-3 fatty acids

Disadvantages:

- **Human health risks**: people comfortable w/ natural foods may be allergic to GM variants
 - Chemical composition of GM foods may be slightly different and alter balance of our diets → alter body chemistry
- **Environmental concerns**: GM foods are currently limited to certain farms, but pollen/animals may escape and spread
- **Unknown consequences**: GM is a recent technology → do we understand enough to avoid unpredictable catastrophe?

F.6 ◊ TEXTURE

F.6.1 ◊ DISPERSED SYSTEMS

- Food **texture** depends on physical properties (hardness, elasticity, etc.)
 - Often affected by **cooking** (meat and veggies become softer as cell structure breaks, cookies harden as H₂O lost).
- Disperse system**: stabilized, macroscopically homogeneous mixture of 2 immiscible phases (creamy texture):
- a) **Liquid-solid: suspensions/sols** (solid particles suspended in liquid, e.g. RBCs and WBCs suspended in blood plasma) and **gels** (liquid particles suspended in solid medium, e.g. fruit jelly, w/ H₂O trapped in protein matrix)
 - b) **Liquid-liquid: emulsions** → stable blend of 2 immiscible liquids, e.g. mayonnaise (suspension of oil droplets in aqueous system)
 - c) **Liquid-gas: foams** (gas bubbles trapped in liquid medium, e.g. whipped cream) and **aerosols** (liquid droplets suspended in gas, e.g. smells in food and cooking)

F.6.2 ◊ EMULSIFIERS

- Why do phases **not** separate? → they often do, only VERY SLOWLY (i.e. by gravity and differing densities)
- **Colloids**: disperse systems which will NEVER separate naturally → often because particles have **charge** and repel (i.e. they will never coalesce and settle)
- **Emulsifiers**: substances used to promote mixing of 2 phases; paired with **stabilisers** (inorganic phosphates like Na_3PO_4) to slow separation process
 - Emulsifiers can bond to **both phases** → found @ surface btwn phases (“**surfactants**”) → e.g. soap molecules
 - **Metal ions** from surroundings incorporated into foams (e.g. egg whites) and act as **stabilisers**
- **Lecithin** → most common emulsifier in food preparation → naturally-occurring **phospholipid** in egg yolk
 - Many **charge centres** and O atoms @ one end (**hydrophilic** → bonds to water) + 2 hydrocarbon chains (break H-bonds in water, but cannot form H-bonds of their own → **hydrophobic** → bonds to non-aqueous phase)
 - Mayonnaise → oil + vinegar + egg yolk all beaten together → **hydrophilic** end bonds to vinegar and HC tails w/ oil
 - Each oil droplet surrounded by lecithin → beating increases SA for surfactant adsorption by creating smaller droplets

F.9 ◊ STEREOCHEMISTRY IN FOOD

F.9.1 ◊ ENANTIOMER NOMENCLATURE

- Enantiomer pair → 1 is **dextrorotatory** (right, + or (*d*)) and other is **laevorotatory** (left, - or (*l*)) – body can metabolize **1**
- Rotation direction NOT indicative of spatial arrangement (**absolute configuration**) → 2 systems for this:
 1. **D,L System**: older convention used for sugars + amino acids
 - **Absolute configuration** of molecule is compared to **glyceraldehyde** (1st abs. config. to be determined, by a guess)
 - **Sugars**: molecule viewed along chain w/ C=O pointed **away**; **D**-isomer has OH on **right** (L has OH on left)
 - **Amino acids**: molecule viewed w/ C-H bond pointing **away** → if COOH, R, NH_2 is in **clockwise** order, then **D**-isomer; → if **anticlockwise**, **L**-isomer → “CORN” acronym
 - Almost **all natural amino acids are L** (tasteless; artificial D amino acids are sweet)
 - Almost **all natural sugars are D** (sweet)
 2. **R,S System**: “CIP” → used for most other compounds. 3 steps:
 - I. Atoms bonded to **chiral carbon ranked** in order of **increasing atomic #** ($\text{H} < \text{C} < \text{N} < \text{O} < \text{F} < \text{C} < \text{Br}$)
 - II. For multiple of same atom (e.g. 1 CH_3 and 1 COOH), **second** atoms used to rank substituents ($\text{CH}_3 < \text{COOH}$ since 3 x # of H is less than # of O) → third, fourth, atoms may also be used if same; also, **double bond** counts as double (COOH = 3 x O)
 - III. Imagine viewing molecule w/ **lowest-rank** substituent pointing **away**
 - if other 3 substituents decrease **clockwise** → **R**-enantiomer (e.g. R-2-bromobutane)
 - if other 3 substituents decrease **anticlockwise** → **S**-enantiomer (e.g. S-2-bromobutane)

F.9.2 ◊ FOOD ENANTIOMERS

- Enantiomers in food, despite **similarity**, have **different smells, tastes, and toxicity** → e.g. **carvone** (a “terpenoid”)
 - **Laevorotatory** R-form → smell and flavour of spearmint
 - **Dextrorotatory** S-form → smell and flavour of caraway seeds
- E.g. **limonene** (related molecule): +(*d*)-limonene is orange-smelling; -(*l*)-limonene is lemon-smelling
- Biosynthesis is **stereospecific** → often, a natural flavour is a **pure enantiomer** (not racemic), e.g. α -ionone (raspberries)
 - Natural material is **stereospecific** R- α -ionone; synthetic is a racemic mixture of R and S (easier to make)
- Enantiomer **toxicity** may vary, e.g. **thalidomide**