

General Chemistry (CH101): Chemistry around Us

Department of Chemistry
KAIST



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Nutrition

Chapter 11

Food that we eat



Why do we need to eat?

- Energy source to power muscle, to send nerve impulses, and to transport molecules
 - Food serves as the **raw materials** (bone, DNA, blood cells, enzymes, and hair)
 - Food supplies nutrients essential for metabolism

Why do we need to drink WATER?

- Plays a role as a reactant, a product, a solvent, a coolant, and thermal regulator
 - 60% of human body





EAT yesterday?

You are what you eat

Eating is not simply filling your stomach!

It is possible to eat to the point of being **overweight**, and still be **malnourished**!

-Malnutrition: Energy may be adequate but **lacking in proper nutrients**

-Undernourishment: Caloric intake is insufficient to meet metabolic needs

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Nutrition Facts

8 servings per container

Serving size 2/3 cup (55g)

Amount per serving

Calories 230

% Daily Value*

Total Fat 8g 10%

Saturated Fat 1g 5%

Trans Fat 0g

Cholesterol 0mg 0%

Sodium 160mg 7%

Total Carbohydrate 37g 13%

Dietary Fiber 4g 14%

Total Sugars 12g

Includes 10g Added Sugars 20%

Protein 3g

Vitamin D 2mcg 10%

Calcium 260mg 20%

Iron 8mg 45%

Potassium 235mg 6%

Macronutrients: fats, carb, proteins

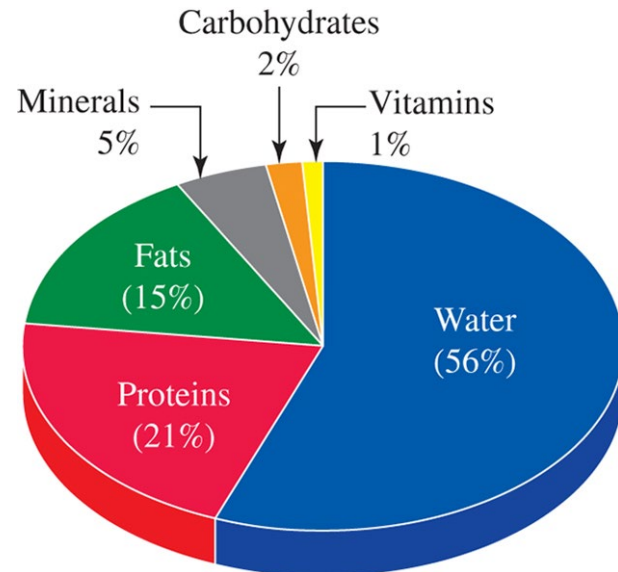
Minerals: in lower conc. but essential

Vitamins: percent = recommended daily requirement

These are all chemicals (organic or “natural”)

You are what you eat

Food	Water	Fat	Carbohydrate	Protein
white bread	37	4	48	8
2% milk	89	2	5	3
chocolate chip cookies	3	23	69	4
peanut butter	1	50	19	25
sirloin steak	57	15	0	28
tuna fish (canned)	63	2	0	30
black beans (cooked)	66	<1	23	9



Composition of the human body
(we are more like steak than chocolate chip!)

YOU ARE WHAT YOU EAT!

Your Turn 11.1

How many kilograms of food will a person (70 kg) eat in their lifetime?



You

How many kilograms of food will a person (70 kg) eat in their lifetime?



ChatGPT

Calculating the exact amount of food a person will consume in their lifetime is a complex task and can vary based on numerous factors such as dietary habits, metabolism, and lifespan. However, I can provide a rough estimate.

On average, an adult consumes around 2,000 to 2,500 calories per day. Let's use the lower end of this range for a conservative estimate. The caloric content of food is approximately 7 calories per gram. Therefore, a person consumes about 7,000 grams (7 kg) of food per day.

Assuming a lifespan of 70 years, the rough estimate for the total food consumption would be:

$7 \text{ kg/day} * 365 \text{ days/year} * 70 \text{ years} \approx 178,850 \text{ kg}$

So, a rough estimate suggests that a person might consume around 178,850 kilograms of food in their lifetime. Keep in mind that this is a simplified calculation and actual consumption can vary widely.

Lipids



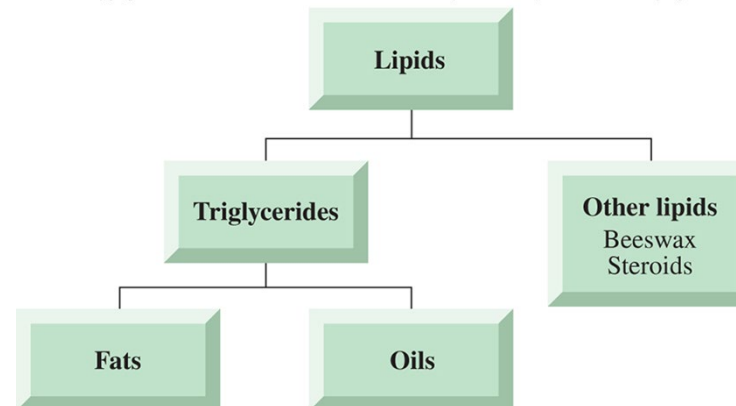
Fats: imparts a desirable flavor and texture
(ice cream, butter, cheese, cakes...)



Oils: cooking oil, olive oil, peanut oil,,,,

→ **Many oils (plant origin) share many of the properties of animal-based fats**
(but oils are liquid at rt, unlike fats)

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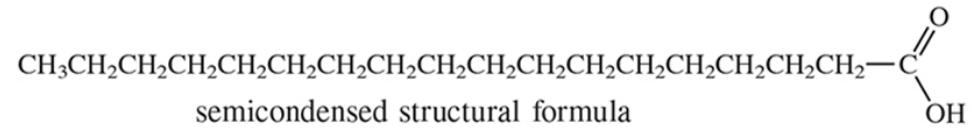


Fats and oils = **triglycerides**
= 3 fatty acids + 1 glycerol

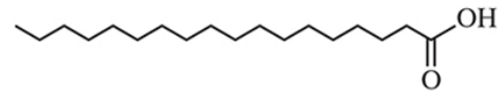
Lipids

- **Fatty acids:** a long hydrocarbon chain + a carboxylic acid group
(greasiness) (-COOH)

condensed structural formula

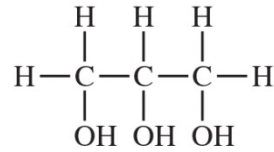


semicondensed structural formula

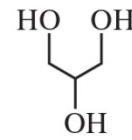


line-angle drawing

- **Glycerol:** Three -OH groups (sticky and syrupy liquid; soaps, lotions)

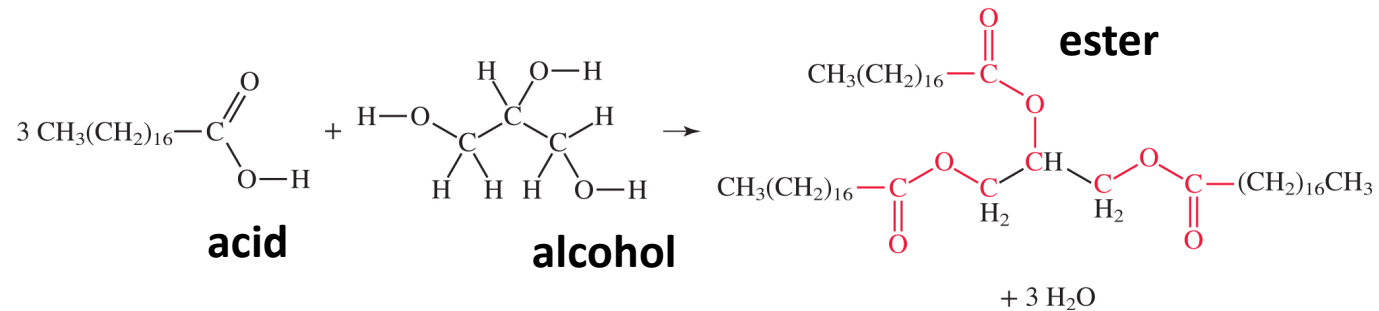


structural formula



line-angle drawing

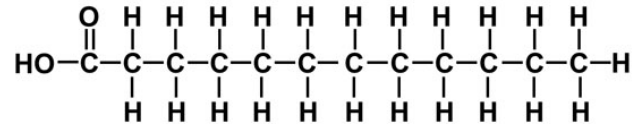
- Triglycerides = 3 fatty acids + 1 glycerol**



Triglycerides

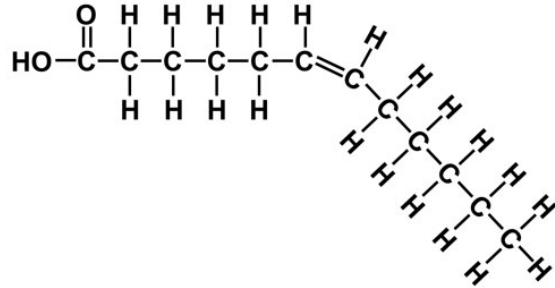
The properties of a fat or oil = determined by the fatty acids incorporated

Saturated Fatty Acid



No double bond (saturated with hydrogen)

Unsaturated Fatty Acid



One or more C=C double bond

All three fatty acids in a triglycerides can be different

→ Many possibilities and properties → fats, oils.....

Triglycerides

Name	Number of C Atoms per Molecule	Number of C=C Double Bonds per Molecule	Melting Point (°C)
<i>Saturated Fatty Acids</i>			
capric acid	10	0	32
lauric acid	12	0	44
myristic acid	14	0	54
palmitic acid	16	0	63
stearic acid	18	0	70
<i>Unsaturated Fatty Acids</i>			
oleic acid	18	1	16
linoleic acid	18	2	-5
linolenic acid	18	3	-11

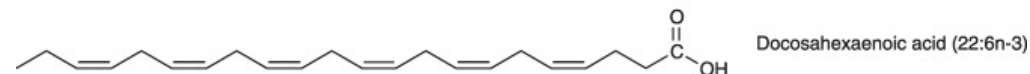
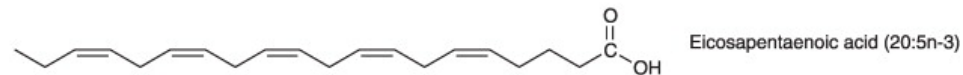
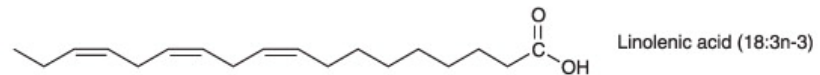
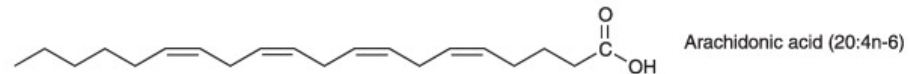
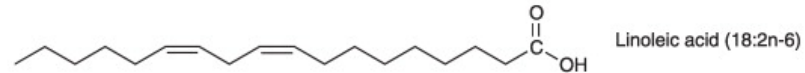
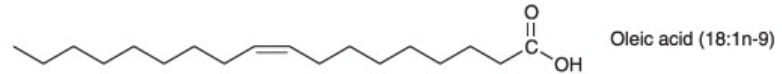
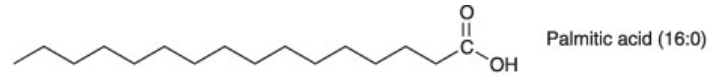
Saturated = more carbon → higher MP

Unsaturated = more C=C → less MP

Many different properties → differ in how they affect your health!

Your Turn 11.4

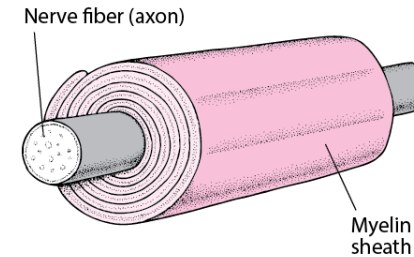
Provide a rationale for decreasing melting points of the fatty acids with increasing degrees of unsaturation



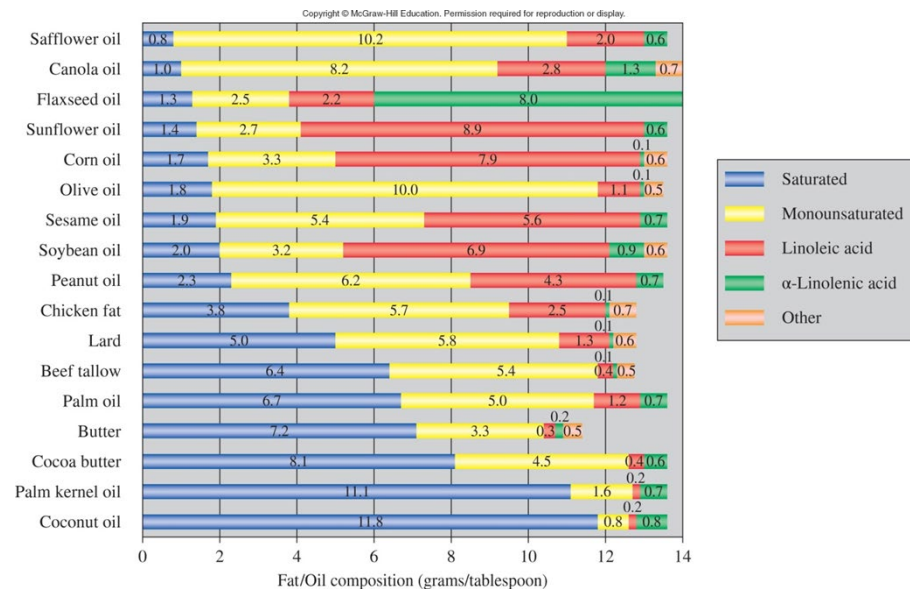
Fats: Good? or Bad?

Fats = high calories fuel

- intensify certain flavors (almost every dessert)
- insulation retaining body heat
- cushion internal organs
- cell membrane and nerve sheaths



Fortunately, our bodies can synthesize almost all fatty acids, except linolenic acid



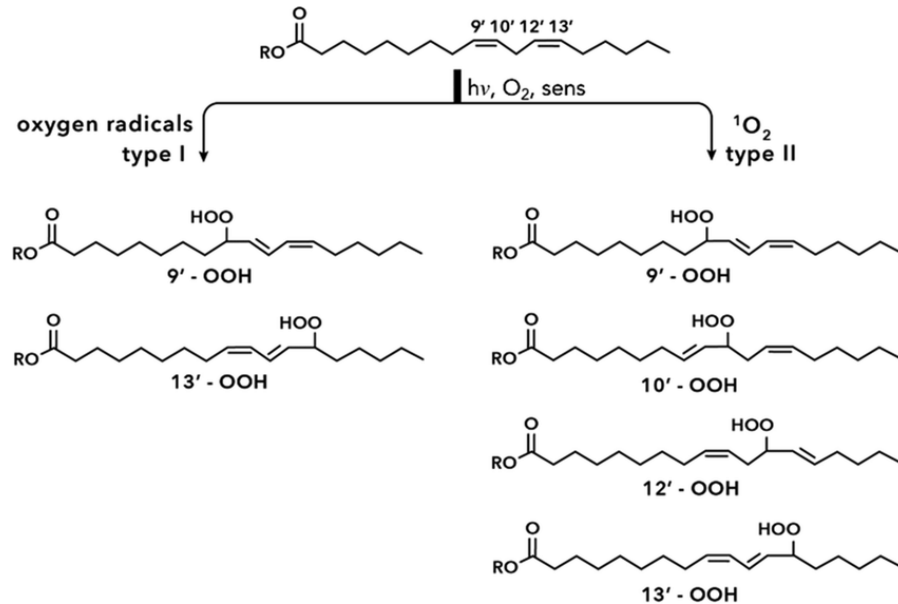
linolenic acid

= essential but plenty in many foods

Oils and fats contain different composition of fatty acids

Fats: Good? or Bad?

Drawback of **unsaturated** fatty acid = easily oxidized by oxygen



- rancid odor over time

- “off-flavor”

-can be advantageous in frying, though.

Second batch frying is better than the first batch.

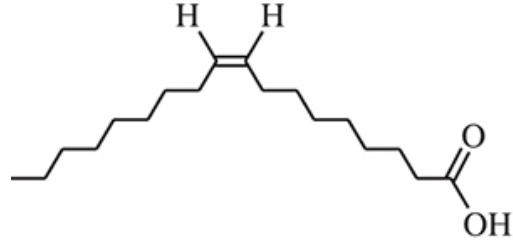
Used oil contains oxidized oil which is **a surfactant!**

That help oil make better contact with food and water



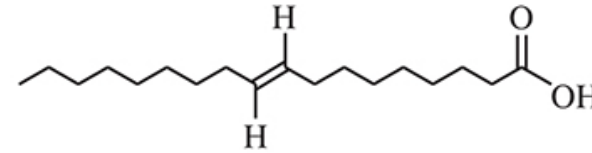
Trans fat

On the **same** side = *cis*



oleic acid, a *cis* fatty acid

On the **other** side = *trans*



elaidic acid, a *trans* fatty acid

Most natural unsaturated fatty acid = *cis* (a plus in a **healthy** diet)

Trans fats → raise the level of "**bad**" **cholesterol** in the blood

- "straight" hydrocarbon → tend to pack well together → solidify well

Eating *trans* fats = increased risk of heart disease

Eating *cis* fats = decreased the risk

Eating saturated fat = increased it slightly

CAUTION!! = "zero grams trans fat" label means <0.5 gram trans fat per serving

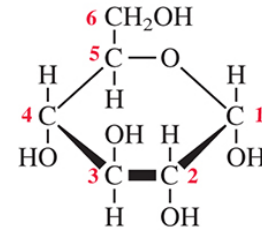
Carbohydrates (from candy to bread)

→ C, H, O (H:O = 2:1)

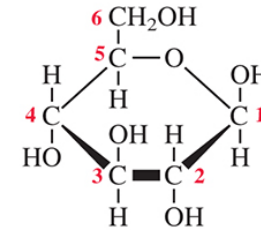
"carbon + water"

Sugars = members of **carbohydrate** family

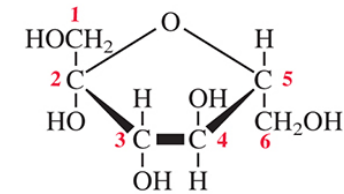
→ i.e., **Glucose** and **fructose**



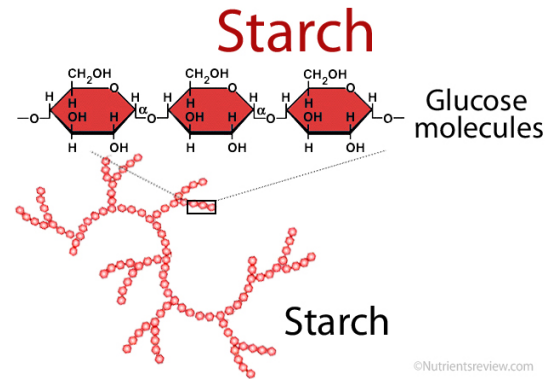
α -glucose
a monosaccharide



β -glucose
a monosaccharide



β -fructose
a monosaccharide

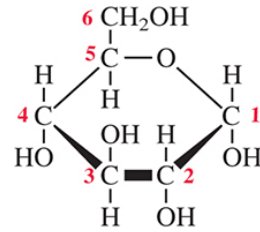


Starch = Polymer of glucose

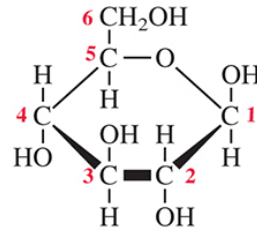
- found in grains, potatoes, and rice
- lacks a sweet taste
- takes a bit to digest
- provide energy to the cells in our bodies

Sugars

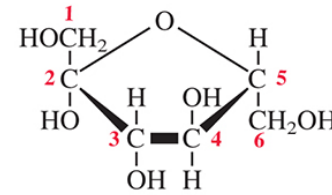
<Monosaccharide>



α -glucose
a monosaccharide



β -glucose
a monosaccharide

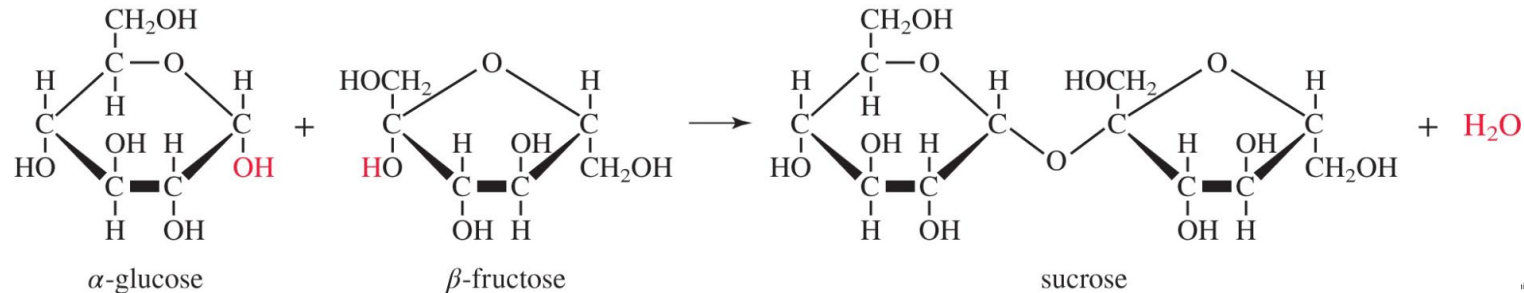


β -fructose
a monosaccharide

All three sugars have $C_6H_{12}O_6$, but different structures = **isomers**
(Glucose/fructose = easier to distinguish) (α -glucose/ β -glucose = difficult)

<Disaccharide>

Table sugar



“double-sugar” through C-O-C linkage

All these sugars are similar in their Calories, but differ in their sweetness
sweetness: fructose (corn syrup) >> glucose/sucrose

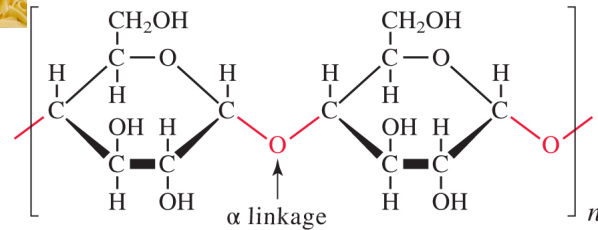


Polysaccharides

= Polymers made up of thousands of monosaccharide units

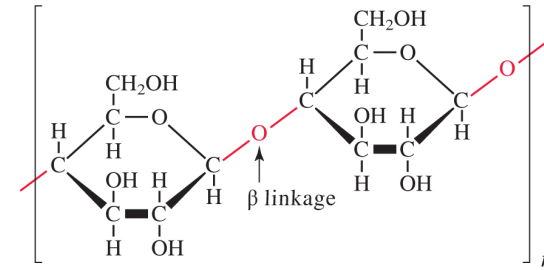


Starch: potatoes, pasta..



(a)

Cellulose: paper, toothpicks..



The subtle difference in how they are connected makes a significant difference

Many mammals (including humans) cannot digest the beta linkage, but the alpha linkage

→ we eat potatoes but cannot dine on grass or trees

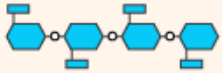
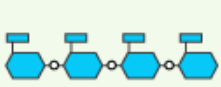
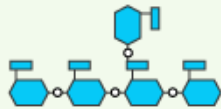
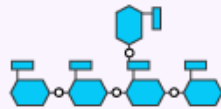
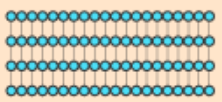

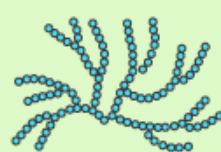
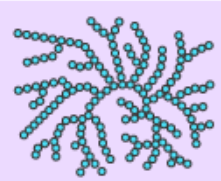
Goats, cows, sheep, and termites can break down cellulose

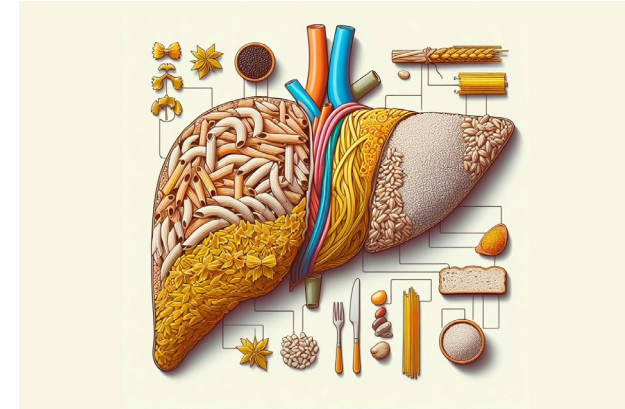
→ Their digestive tracts contain bacteria that decompose cellulose into glucose

Polysaccharides

= Polymers made up of thousands of monosaccharide units

Glycogen: similar to starch in structure, but loner and more branched.

	Cellulose	Starch		Glycogen
		Amylose	Amylopectin	
Source	Plant	Plant	Plant	Animal
Subunit	β -glucose	α -glucose	α -glucose	α -glucose
Bonds	1-4	1-4	1-4 and 1-6	1-4 and 1-6
Branches	No	No	Yes (~per 20 subunits)	Yes (~per 10 subunits)
Diagram				
Shape				



It accumulates in muscles and liver → quick source of internal energy
(vitally important!)

In diet books, “good carb” and “bad carb”

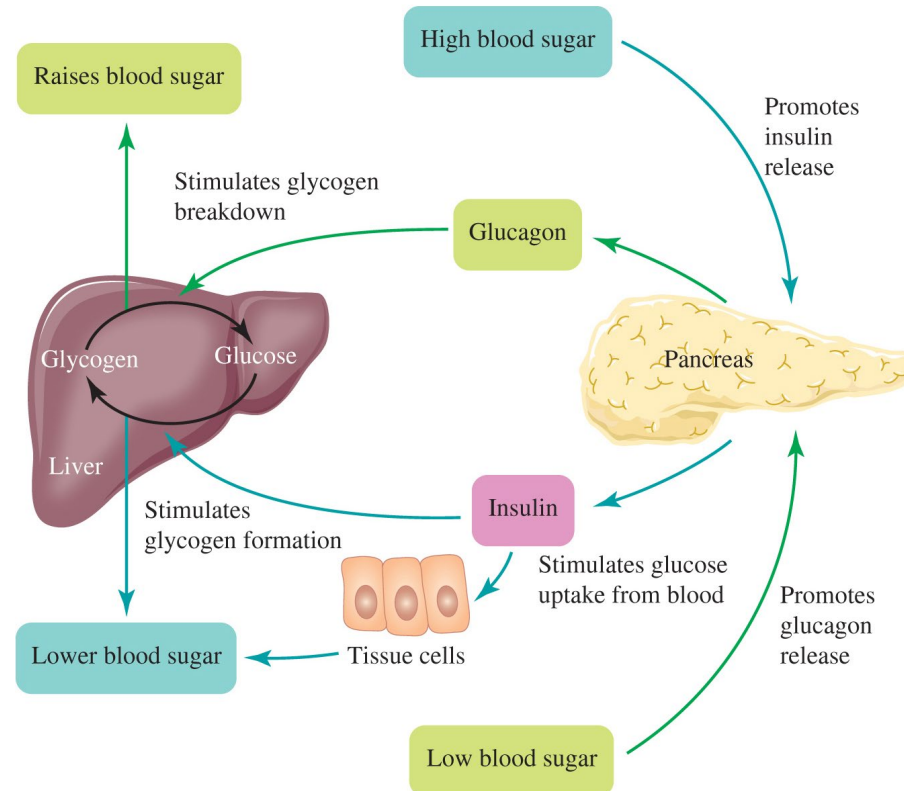
“**Bad**” carb = quickly increase blood sugar → **insulin** → formation of glycogen (store)

If the stored sugar is not used immediately, it's converted into fat and stored in your cell!

“**Low-carb**” diet → low blood sugar → **glucagon** → use of stored glucose!

-Also, consumption of proteins promotes glucagon release

“Good” carb should release sugar slowly!



"Added" sugar

We all love sweetness → We are eating too much sugar!

Does it matter which sugar you consume?

As we discussed, **polysaccharides** can be better than **simple sugars**

Sugar in foods = natural sugar in food + **added sugar by manufacturers**

Nutrition Facts			
Serving Size 2/3 cup (55g)			
Servings Per Container About 8			
Amount Per Serving			
Calories 230		Calories from Fat 72	
		% Daily Value*	
Total Fat	8g		12%
Saturated Fat	1g		5%
Trans Fat	0g		
Cholesterol	0mg		0%
Sodium	160mg		7%
Total Carbohydrate	37g		12%
Dietary Fiber	4g		16%
Sugars	12g		
Protein	3g		
Vitamin A			10%
Vitamin C			8%
Calcium			20%
Iron			45%
* Percent Daily Values are based on a 2,000 calorie diet. Your daily value may be higher or lower depending on your calorie needs.			
	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

(a)

Nutrition Facts	
8 servings per container	
Serving size	2/3 cup (55g)
Amount per serving	
Calories	230
% Daily Value*	
Total Fat	8g 10%
Saturated Fat	1g 5%
Trans Fat	0g
Cholesterol	0mg 0%
Sodium	160mg 7%
Total Carbohydrate	37g 13%
Dietary Fiber	4g 14%
Total Sugars	12g
Includes 10g Added Sugars	20%
Protein	3g
Vitamin D	2mcg 10%
Calcium	260mg 20%
Iron	8mg 45%
Potassium	235mg 6%
* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.	

(b)

13% of the total Calories consumed are
from added sugars
= **17~22 teaspoons of added sugar daily!!!**

Sugar substitutes

High-fructose corn syrup (HFCS): used to sweeten many foods and drinks

→ Free monosaccharides in HFCS provide better flavor, stability, freshness, color, texture...

HFCS is really sweet → public concern!

Lactose	Maltose	Glucose	Honey	Sucrose	Fructose
16	32.5	74.3	97	100	173

Scientific studies say “**metabolically, HFCS appears to be similar to sucrose in our bodies**”

NONETHELESS, due to public concerns Yoplait, Gatorade, PepsiCo, and Hershey’s phased out the use of HFCS, replacing it with sucrose

<Artificial sweeteners>

***when sucrose = 1**

Acesulfame potassium	Aspartame	Neotame	Saccharin	Sucralose
200	200	7,000 to 13,000	300	600

Aspartame = same Calories per gram as sucrose = 200X sweet = 1/200 Calories... = **~0 Cal**

Your Turn 11.19

- a. Propose a reason why glucose, fructose, and sucrose differ in their degree of sweetness

<https://youtu.be/FaBFyEa8-el>

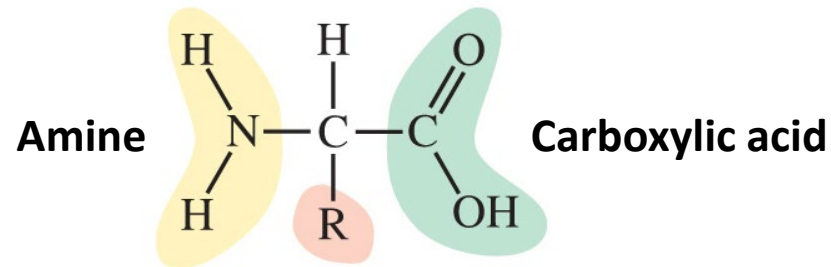
- b. Explain why these sugars are almost identical in their Calories per gram.

Lactose	Maltose	Glucose	Honey	Sucrose	Fructose
16	32.5	74.3	97	100	173

Proteins

- Components in hair, skin, and muscle
- Transport oxygen, nutrients, and minerals
- Enzymes, and many hormones.

Protein = a polymer of **amino acid** (monomer) = polypeptide

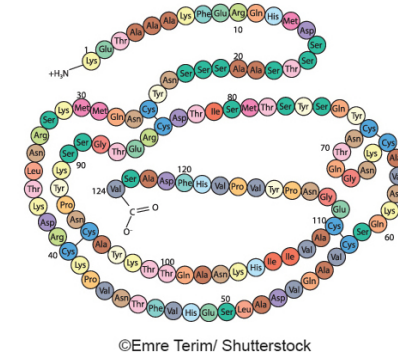


Side chain

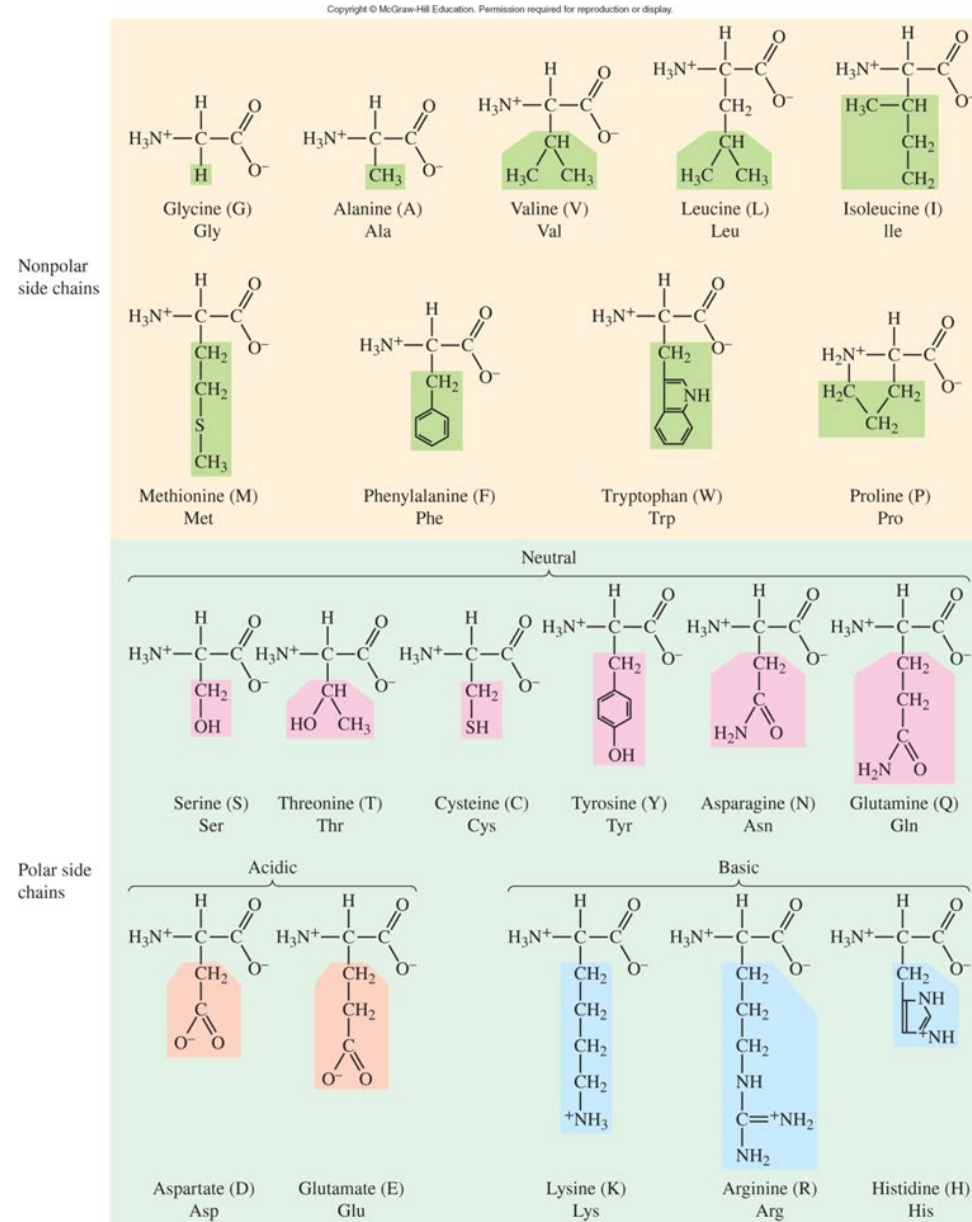
→ It governs the chemical properties

- Polar: hydrophilic (bonds with water)
- Nonpolar: hydrophobic (repelled by water)

Primary structure of ribonuclease



Amino acids

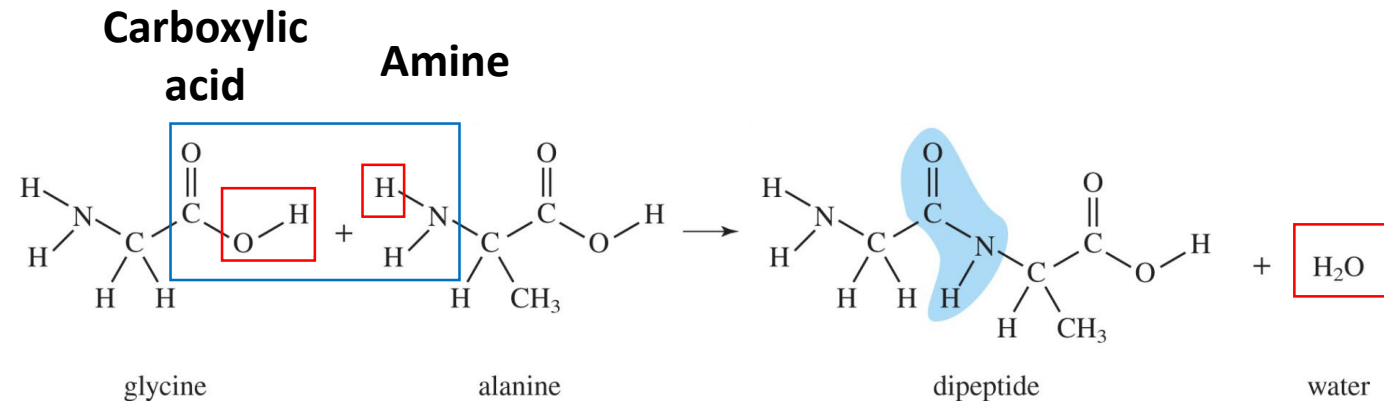


Polar side chains

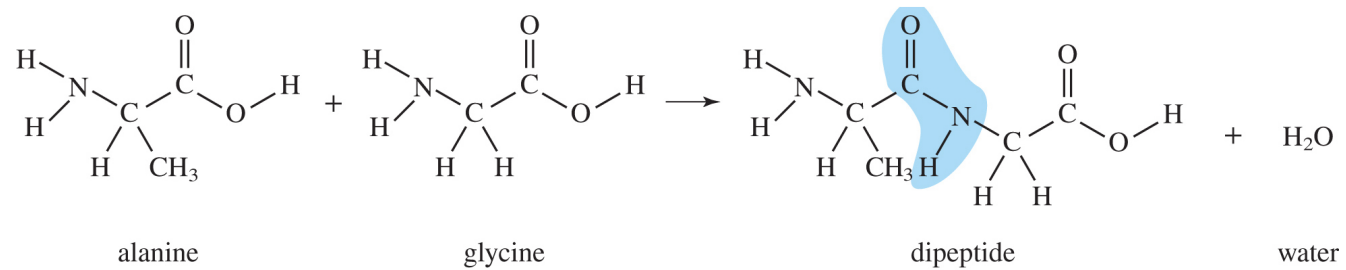
- Ionic/H-bonds
- Acidic (acids) or basic (amines)
- Can be charged (i.e., Lys)

Peptides

= Polymers of amino acids



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“the order of amino acid residues in a peptide makes a difference!”

A particular protein structure depends on the types of amino acids and the sequence of it

i.e., (a, e, t) → eat, ate, tea

Essential amino acids

= required for protein synthesis, but are **not synthesized** by human body
(9 amino acids out of 20)

Normally, the body does not store a reserve supply of protein

→ **Must be eaten regularly**
(The balance matters!!!)

Sufficient quantity and suitable quality of proteins

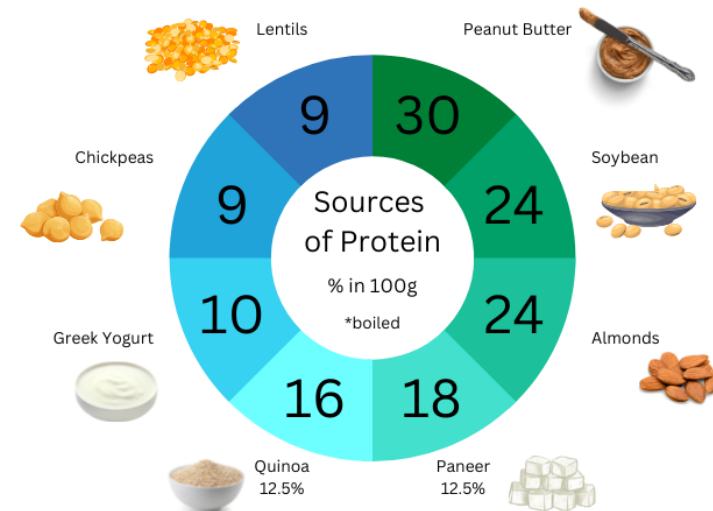
- Beef, fish, and poultry = **the same proportions of essential amino acids** with the one in human
- Most people depend on grains and vegetable crops = **some can be lacking = DIVERSIFY!**
(i.e., Mexican diet tend to be rich in corn → low in tryptophan)

- **Vegetarians** → must use “**protein complementarity**”

i.e., Peanut butter sandwich:

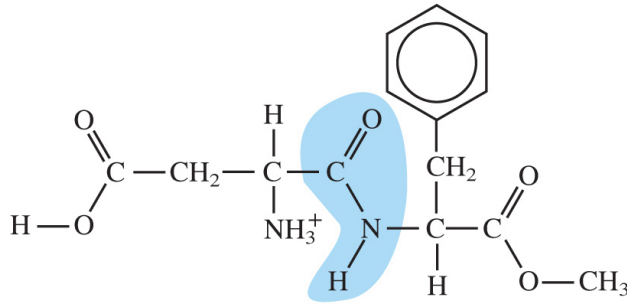
Bread = lysine↓/methionine↑

peanut = lysine ↑/methionine↓



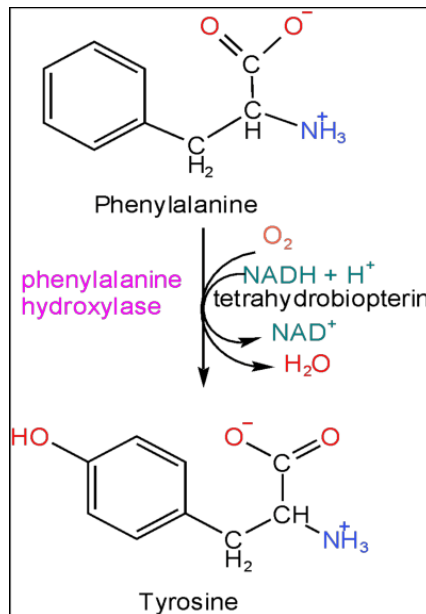
? + ? = aspartame

Aspartame



Aspartame (a sugar substitute) is a DIPEPTIDE!

- One of the most highly studied food additives
- safe for the vast majority of consumers



Phenylketonuria (genetically unable to process Phe)

→ Phe in blood rises

→ Phe converts to phenylpyruvic acid

→ severe mental retardation

Thus, **phenylketonurics** must put on a diet severely **limited in Phe**

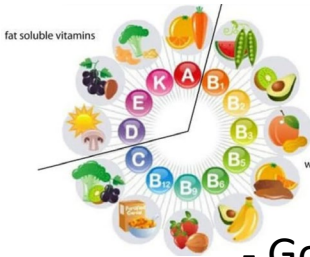
(still need a minimum amount of it)

→ **No Diet Coke!!**

Phenylalanine

= an essential amino acid

= converted into tyrosine

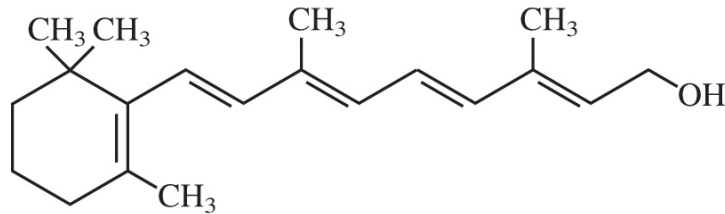


Vitamins

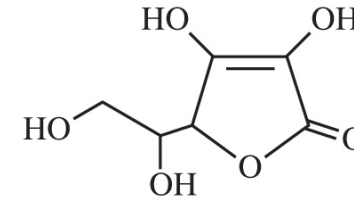
= needed only in miniscule amounts but still are essential

- Good for health, proper metabolic functioning, and disease prevention...

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vitamin A, a lipid-soluble vitamin



vitamin C, a water-soluble vitamin

Vitamin A, D, E, and K (fat-soluble)

- stored in cells rich in lipids
- if swallowed in excess, it's toxic!

Vitamin B, and C (water-soluble)

- excreted in the urine rather than stored
- need to eat frequently

*a balanced diet provides the necessary vitamins except **vitamin D**, which is synthesized in the **skin by using sunlight**

**** Many vitamins are coenzymes**

= work in conjunction with enzyme to enhance their activity

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= ionic compounds

- Macrominerals: Ca, P, Cl, K, S, Na, and Mg

- Microminerals: Fe, Cu, and Zn

- Trace minerals: I, F, Se, V, Cr, Mn, Co, Ni, Mo, B, Si, and Sn

[illegible]

 Trace minerals

- $\text{Ca} + \text{P} + \text{F} \rightarrow \text{bone}$
- blood clotting
- muscle contraction
- transmission of nerve impulses

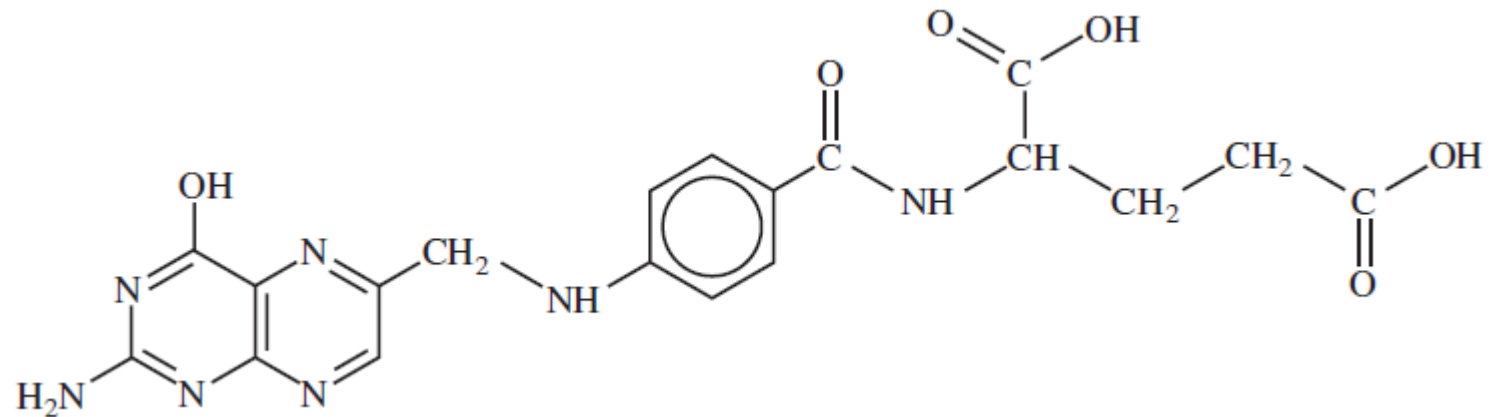
- you need to ingest 2 g of K^+ a day
- abundant in oranges, bananas, and tomatoes

Your Turn 11.14

This vitamin (folic acid) is particularly important for pregnant women.

Do you expect that it would be soluble in fat? Or in blood stream (water)?

Explain your reasoning



Your Turn 11.15

Can you turn orange from eating large amounts of carrots due to water-soluble or fat-soluble components in these food?



Your Turn 11.16

“Megadoses of vitamin C”

Share your experience if you have any.



Vitamin C megadosage

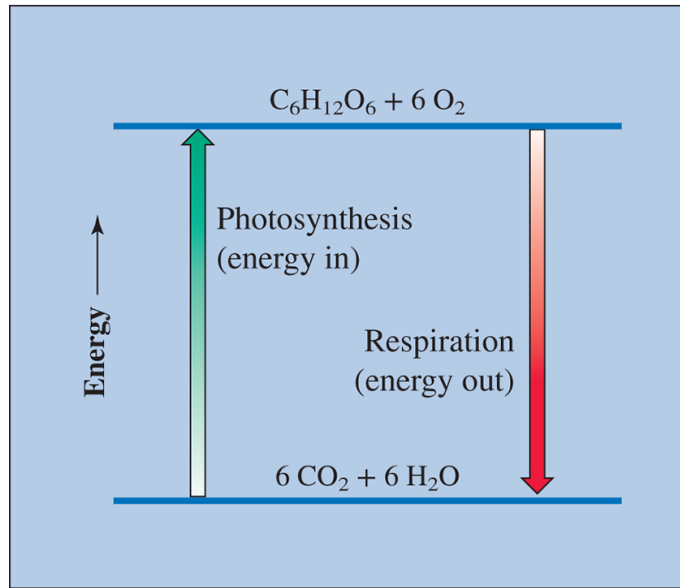
[Article](#) [Talk](#)

From Wikipedia, the free encyclopedia

Vitamin C megadosage is a term describing the consumption or injection of [vitamin C](#) (ascorbic acid) in [doses](#) well beyond the current United States [Recommended Dietary Allowance](#) of 90 milligrams per day, and often well beyond the [tolerable upper intake level](#) of 2,000 milligrams per day.^[1] There is no scientific evidence that vitamin C megadosage helps to cure or prevent cancer, the common cold, or some other medical conditions.^{[2][3]}

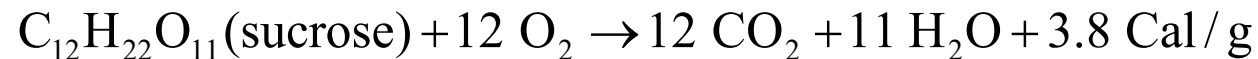
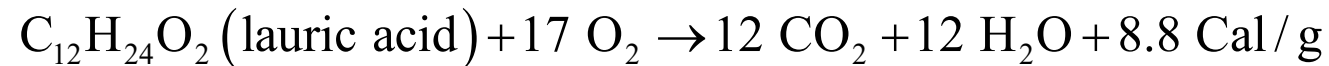
Food for energy

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In addition to **supplying** sufficient energy,
regulating the energy-release is critical
(without it, your body temp would fluctuate)

Table 11.7 Average Energy Content of Macronutrients	
Macronutrient	Energy Content (Cal/g)
fats	9
carbohydrates	4
proteins	4



- Both compounds have the same number of C & H (nearly)**
→ C & H combine with oxygen to form CO_2 and H_2O
→ More oxygen is required to burn fat → More energy is released overall

*In the language of chemistry = the sugar is more “**oxidized**” than the fatty acid*

Table 11.8		Estimated Calorie Requirements (United States)	
ACTIVITY LEVEL			
Age (yr)	Sedentary*	Moderately Active†	Active‡
Females			
14–18	1800	2000	2400
19–30	2000	2000–2200	2400
31–50	1800	2000	2200
51+	1600	1800	2000–2200
Males			
14–18	2200	2400–2800	2800–3200
19–30	2400	2600–2800	3000
31–50	2200	2400–2600	2800–3000
51+	2200	2200–2400	2400–2800

**Sedentary* means a lifestyle that includes only the light physical activity associated with typical day-to-day life.

†*Moderately active* means a lifestyle that includes physical activity equivalent to walking about 1–3 miles per day at 3–4 miles per hour, in addition to the light physical activity associated with typical day-to-day life.

‡*Active* means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3–4 miles per hour, in addition to the light physical activity associated with typical day-to-day life.

Source: *Dietary Guidelines for Americans USDA 2005*

Table 11.9		Energy Expenditure for Common Physical Activities*	
Moderate Physical Activity	Cal/h	Vigorous Physical Activity	Cal/h
hiking	370	running (10 mph)	1050
light gardening/yard work	245	heavy yard work (chopping wood)	440
dancing (ballroom, fast)	315	swimming (freestyle laps)	510
golf (walking, carrying clubs)	245	aerobics	480
bicycling (<10 mph)	279	bicycling (12–14 mph)	559
walking (3.5 mph)	196	jogging (5 mph)	490
weight lifting (light workout)	140	weight lifting (vigorous workout)	350
stretching	105	basketball (competitive game)	490

*Values taken from CalorieLab, and include both resting metabolic rate and activity expenditure for a 154-pound (70-kg) person. Calories burned per hour are higher for persons heavier than 154 pounds and lower for persons who weigh less.

Food safety



Unhealthy eating = 400,000~500,000 deaths occur every year in the US

Food poisoning = 3000~150,000 cases (bacteria, viruses, parasites, and chemical toxins..)

Accumulative effect is more severe!

→ Processing, transportation, handling, and storage should be processed carefully

- **Food surveillance** = random samples are taken from grocery stores
- **Total diet survey** = Samples of consumers' meals are analyzed for contaminants
- **Enforcement sampling** = Samples are taken when there is concern that an issue may exist

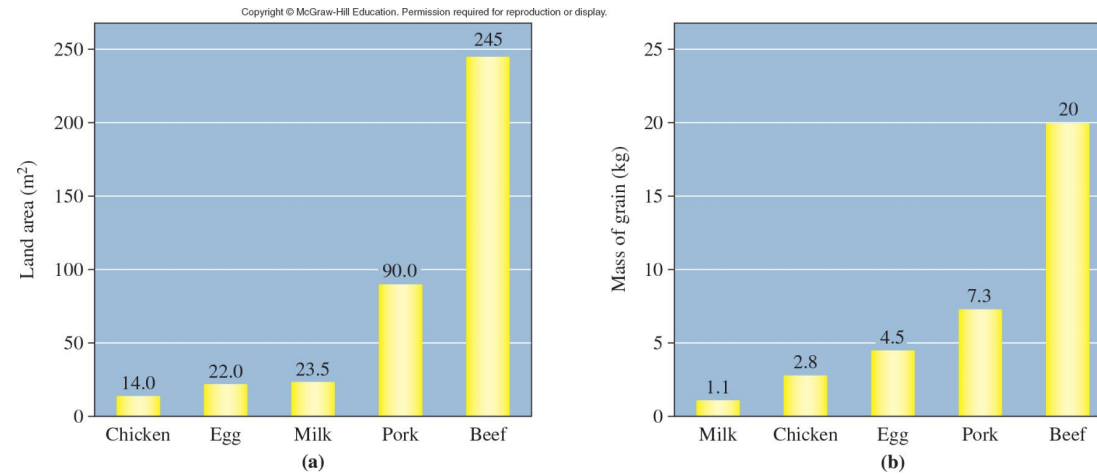
Legislation and monitoring are more complex in our globalized society

→ **Rigorous testing is required at major ports of entry**

Real costs of food production

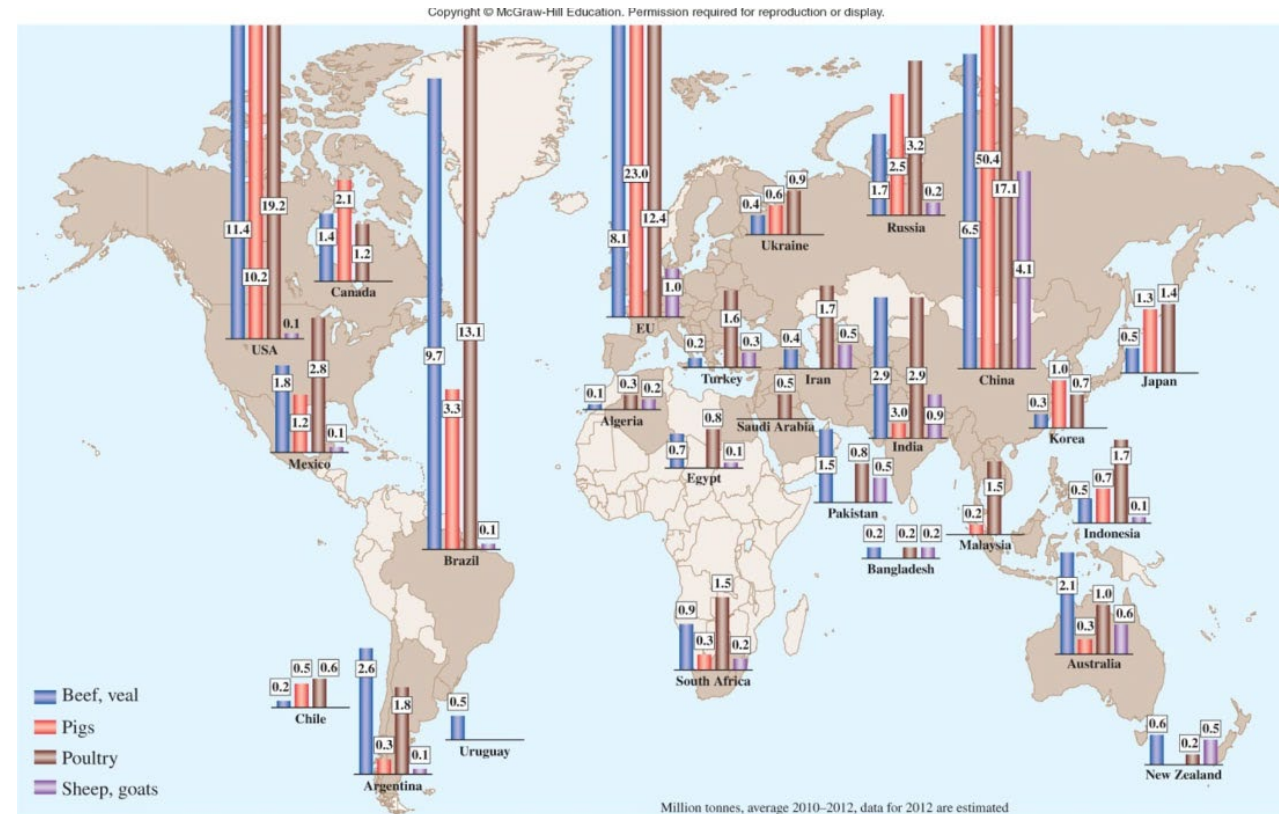
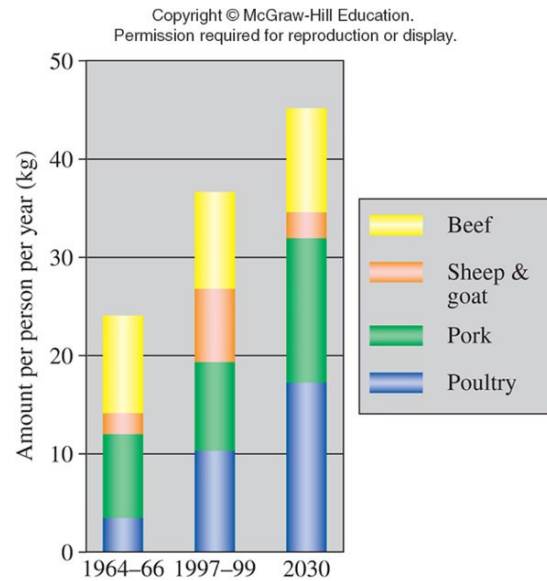
1 kg of beer on the table = required 15,000 L of water

It's not that cattle drink this much water



To bring 1kg of food, this much land/grain is needed

Real costs of food production



In 2030, we need 358 kg of grain per person * 8 billion people = **2.9 trillion kg**
(The world grain production = **2.3 trillion kg** in 2017)

We need to find a way to overcome the shortfall!

The carbon footprint of foods

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Eating locally vs “Food miles”

1. Eating local means more for the local economy.
2. Locally grown produce is fresher and tastes better.
3. Locally grown fruits and vegetables have longer to ripen.
4. Buying local food keeps us in touch with the seasons.
5. Supporting local providers supports responsible land development.

“Food miles”

Food from your back yard

vs

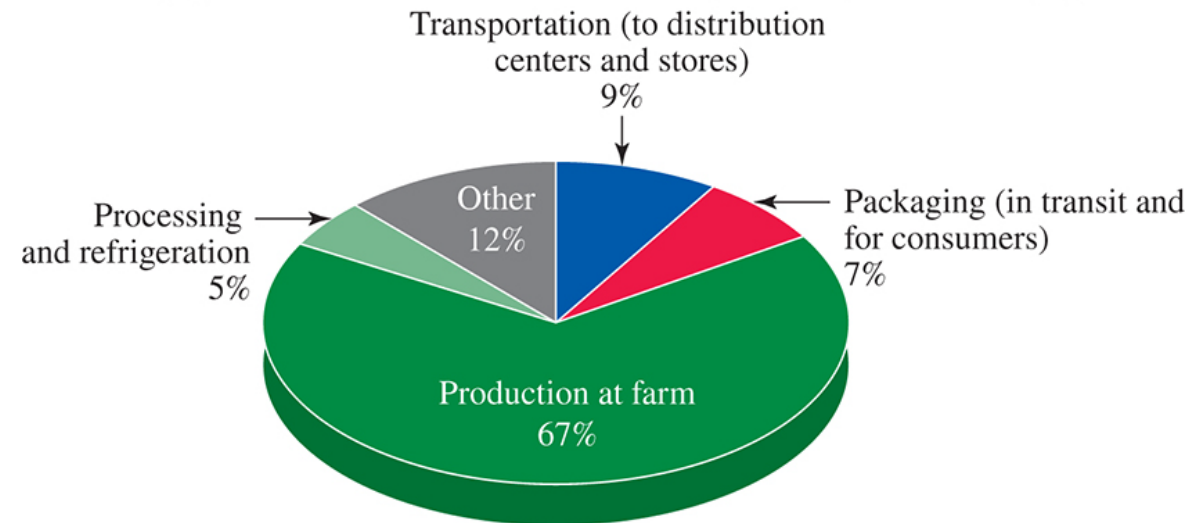
Food from another country

That results in varying degree of energy use and atmospheric emissions

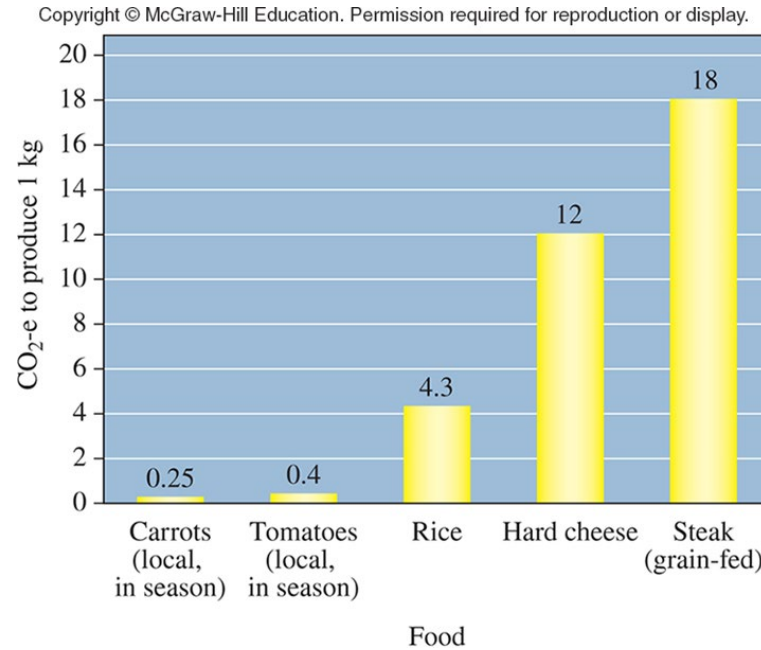
Would it help if all food were produced locally?

NOT NECESSARILY!!

(growing tomatoes in a greenhouse can be worse than transporting tomatoes)



Carbon footprint



The majority of the carbon footprint comes from food production on farm

i.e., operating farm machinery, fertilizer stimulates microbes, livestock produces methane..

Replacing a single meat-based meal with a vegetarian option

→ Equivalent of driving about 1200 fewer miles annually

Nitrogen footprint



Source: Photo by George E. Marsh, NOAA,
Dept. of Commerce

In previous decades, a tillage rotation was common

However, frequent plowing exposes the soil to erosion.

→ Agricultural practices have now shifted toward **continuous cropping**

Higher rates of nitrogen based fertilizer are required to maintain high crop yield!

contains **N, P, K, S, C, H**

Why do we need nitrogen in fertilizer, while it's abundant in the air?

Reactive nitrogen

In order to grow, plants need "reactive nitrogen"

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Table 11.13 Some Reactive Forms of Nitrogen*	
Name	Chemical Formula
nitrogen monoxide (nitric oxide)	NO
nitrogen dioxide	NO ₂
dinitrogen monoxide (nitrous oxide)	N ₂ O
nitrate ion	NO ₃ ⁻
nitrite ion	NO ₂ ⁻
nitric acid	HNO ₃
ammonia	NH ₃
ammonium ion	NH ₄ ⁺

*These forms of nitrogen all are naturally occurring.

Thus, N₂ in the atmosphere is required to be converted to those reactive molecules!

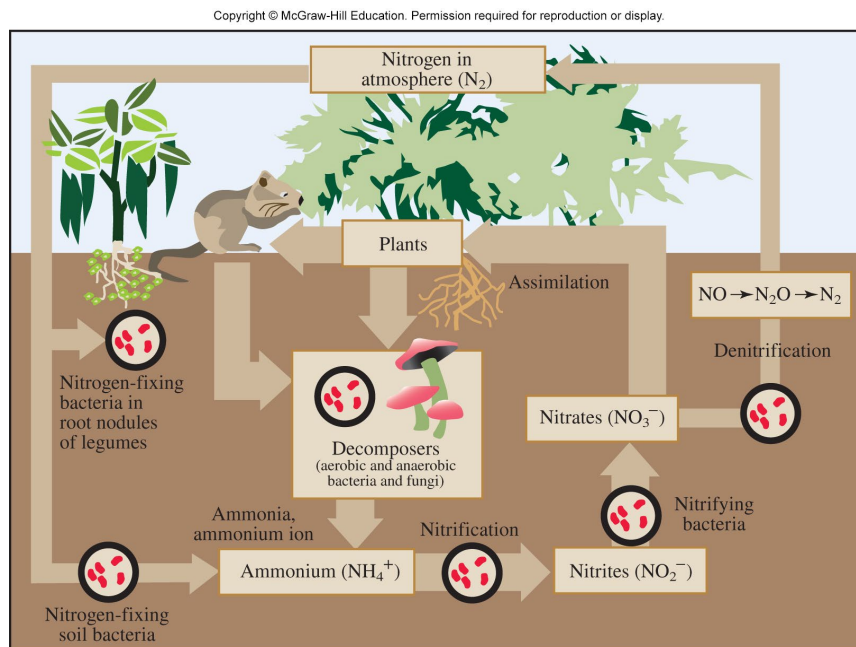
Nitrogen cycle

Nitrogen-"fixing" (removing) bacteria:

- it removes N_2 from the air and converts it to NH_3
- the bacteria live on or near the roots of alfalfa, beans, and peas



Two forms of reactive nitrogen that most plants can absorb



These molecules are needed for plant

→ Bacteria in the soil cannot supply
for the continuous cropping

→ Fertilizers are required

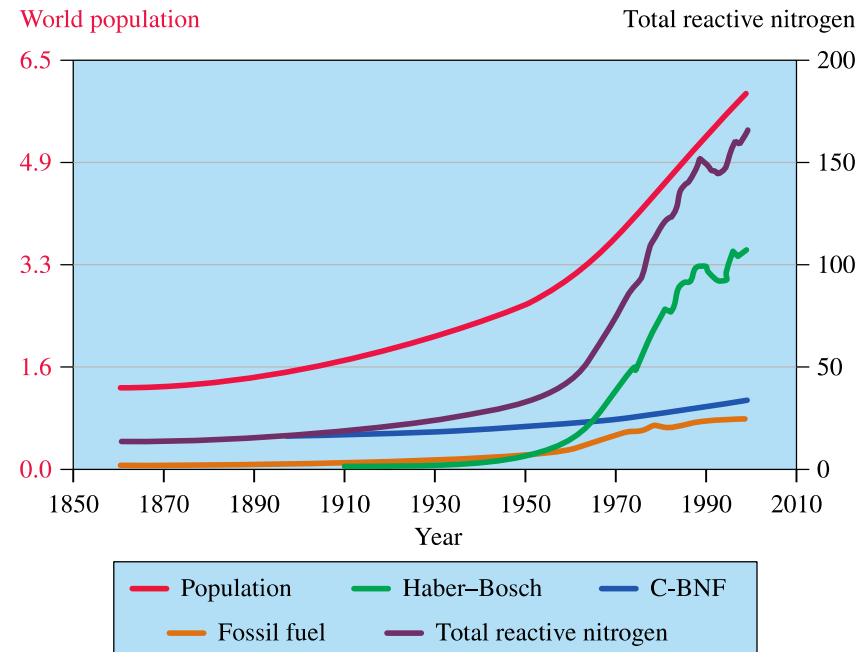
- a nitrogen-rich deposit from birds

- Haber-Bosch >> large-scale production



Nitrogen Hydrogen Ammonia

Nitrogen supply and world population



Total reactive nitrogen = fossil fuels (energy production) + fertilization (food production)
→ Parallel the growth in world population!

However, the reactive forms of nitrogen can be....

- increasing the acidity of the atmosphere
- increasing the concentration of a greenhouse gas (N_2O)
- a pollutant of a water supply

Your Turn 11.39

Based on the topics discussed in this chapter, assess your food choices yesterday.

How would you want to change it?

- Can human utilize the bacteria that digest cellulose? Adv and disadv?
- List five of unregulated food additive and describe the purpose for them and the claimed health implications.
- Do supplementary vitamin/mineral pills helpful? Discuss pros and cons
- Does drinking "protein shake" help building your muscle? What's in there? And how does it work?