Contents

# APPENDICES

**Only because water is so cohesive can trees raise it hundreds of feet off the ground.** Individual California coast redwoods (*Sequoia sempervirens*) may grow to heights of 360 feet, taller than a 25-story building.

Appendix is "an addition to a document or book (generally at the end) which supplements or illustrates the text"

[*Source : (one of the meanings) : The New International* ***Webster's Dictionary*** *of the English Language, Trident Press International*]

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# APPENDIX I

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# APPENDIX II

## GREEK ALPHABET*

| *Greek letter* | *Greek name* | *English equivalent* | *Greek letter* | *Greek name* | *English equivalent* |
|---|---|---|---|---|---|
| Α, α | Alpha | a | Ν, ϖ | Nu | n |
| Β, β | Beta | b | Ξ, ξ | Xi | x |
| Γ, γ | Gamma | g | Ο, *0* | Omicron | ŏ |
| Δ, δ | Delta | d | Π, π | Pi | p |
| Ε, ε | Epsilon | ĕ | Ρ, ρ | Rho | r |
| Ζ, ζ | Zeta | z | Σ, σ | Sigma | s |
| Η, η | Eta | ē | Τ, τ | Tau | t |
| Θ, θ | Theta | th | ϒ, υ | Upsilon | u |
| Ι, ι | Iota | i | Φ, φ | Phi | ph |
| Κ, κ | Kappa | k | Χ, χ | Chi | ch |
| Λ, λ | Lambda | I | Ψ, ψ | Psi | ps |
| Μ, μ | Mu | m | Ω, ω | Omega | ō |

* Greek letters are preferably used to indicate the positions of substituents in compounds described by trivial names, *e.g.,* α-hydroxypropionic acid (lactic Kcid). They are used to indicate the *class* of compound, *e.g.*, γ- and δ-lactones. The use of Greek letters to indicate the positions of substituents in a chain should, however, be avoided. Instead, the numerals should be used.

# APPENDIX III

## EXPONENTIAL NOTATION

Exponential notation is used to deal with very large and very small numbers. An **exponent** is a symbol written to the right and above a number or mathematical expression; it indicates number of times that figure is to be multiplied by itself. An exponent is also called the **power** of a number.

(*a*) *For numbers greater than one*, the exponents is positive and is equal to the number of zeroes following the one.

$$10 = 10^1 = \text{ten}$$

$$100 = 10^2 = \text{one hundred}$$

$$1000 = 10^3 = \text{one thousand}$$

$$10000 = 10^4 = \text{ten thousand}$$

$$1000000 = 10^6 = \text{one million}$$

$$1000000000 = 10^9 = \text{one billion}$$

(*b*) *For numbers smaller than one*, the exponent is negative and is equal to the number of places the one is to the right of the decimal point.

$$.1 = 10^{-1} = 1 \text{ tenth}$$

$$.01 = 10^{-2} = 1 \text{ hundredth}$$

$$.001 = 10^{-3} = 1 \text{ thousandth}$$

$$.0001 = 10^{-4} = 1 \text{ ten-thousandth}$$

$$.0000001 = 10^{-6} = 1 \text{ millionth}$$

$$.0000000001 = 10^{-9} = 1 \text{ billionth}$$

Any large or small number may be expressed as the product or a more convenient-sized number and a power of 10. Thus, 357 may be expressed as $3.57 \times 100 = 3.57 \times 10^2$. Similarly, $357{,}000{,}000 = 357\times 10^6$, or $3.57 \times 10^8$.

In decimals smaller than one, the decimal point is moved to the right, and the resulting number is multiplied by a negative power of 10 equal to the number of places the decimal point was moved : $.0357 = 3.57 \times 10^{-2}$ or $35.7 \times 10^{-3}$; $.0000357 = 3.57 \times 10–5$ or $35.7 \times 10^{-6}$.

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# APPENDIX IV

## THE INTERNATIONAL SYSTEM OF UNITS
## (System international d'unites)

The International system of unite is a metric system based on the *metre, kilogram and socond* (m.k.s. system) in place of the *centimetre, gram and second* (the old c.g.s system). These SI units (Syste'me International d'Unite's) were approved in 1960 by The General Conference of Weights and Measures and are being adopted by the scientific laboratories throughout the world. They are a *coherent system of units* so that if two unit quantities are multiplied or divided, then the answer is the unit of the resultant quantity. In this way, the number of multiplies and submultiples of units now in use, will be reduced.

### A. Basic Units

This system is now based on 8 base units in relation to 8 basic kinds of quantity (Table 1). Other units are based on these basic unit. The primary units of **length** is the *metre*. A metre is the distance between two lines, under standard conditions, engraved on a prototype preserved in the Bureau International des Poids et Measures, Se'vres, France.

The primary unit of **mass** is the *kilogram*, which is the mass of the prototype preserved in the same place.

**Table 1.** **The 8 Base Units**

| *S.N.* | *Physical Quantity* | *Unit* | *Symbol* |
|---|---|---|---|
| 1. | Length | Metre | m |
| 2. | Mass | Kilogram | kg |
| 3. | Time | Second | s |
| 4. | Amount of substance | Mole | mol |
| 5. | Thermodynamic temperature | Kelvin | K |
| 6. | Electric current | Ampere | A |
| 7. | Luminous intensity | Candela | cd |
| 8. | Katalytic amount | Katal | kat |

### B. Derived SI Units

Besides the above basic units, there are also a number of derived SI units, obtained by appropriate combination of these basic units. For convenience, these derived units are given special names (Table 2).

**Table 2.** **Some Derived SI Units***

| *S. N.* | *Physical Quantity* | *Unit* | *Symbol* | *Definition* |
|---|---|---|---|---|
| 1. | Frequency | Hertz | Hz | $S^{-1}$ |
| 2. | Force | Newton | N | $kg\ m\ s^{-2}$ |
| 3. | Energy | Joule | J | $kg\ m^2\ s^{-2}$ |
| 4. | Pressure | pascal | Pa | $kg\ m^{-1}\ s^{-2}$ |
| 5. | Power | Watt | W | $kg\ m^2 s^{-3}$ |
| 6. | Electric charge | Coulomb | C | A s |
| 7. | Electric potential | Volt | V | $kg\ m^2\ s^{-3}\ A^{-1}$ |
| 8. | Electric resistance | Ohm | Ω | $kg\ m^2\ s^{-3}\ A^{-2}$ |
| 9. | Electric capacitance | Farad | F | $A^2\ s^4\ kg^{-1}\ m^{-2}$ |
| 10. | Customary temperature | Degree Celsius | ºC | °C = K – 273.15 |

* None of these units take the plural form, so that 2 volts is written as 2V, not 2 Vs and 3 metres is written as 3m, not 3ms.

## C. Prefixes for the SI Units

Sometimes units may be too large or too small and in such cases in other to avoid writing too many zeros, a prefix is placed before the symbol of the unit. The recommended multiples or fractions of a unit change mostly by 1,000 each time (Table 3). Thus, 0.000025 mol is written 25 µmol and 12,500 m is written 12.5 km.

**Table 3. Prefixes denoting decimal factors for the SI Units***

| *Magnitude Multiples* | *Prefix* | *Symbol* |
|---|---|---|
| $10^{24}$ | yotta | Y |
| $10^{21}$ | zetta | Z |
| $10^{18}$ | exa | E |
| $10^{15}$ | peta | P |
| $10^{12}$ | tera | T |
| $10^{9}$ | giga | G |
| $10^{6}$ | mega | M |
| $10^{3}$ | kilo | k |
| $10^{2}$ | hecto | h |
| $10^{1}$ | deca | da |
| **Fractions** | | |
| $10^{-1}$ | deci | d |
| $10^{-2}$ | centi | c |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro† | µ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |
| $10^{-15}$ | femto | f |
| $10^{-18}$ | atto | a |
| $10^{-21}$ | zepto | z |
| $10^{-24}$ | yocto | y |

* These prefixes are applied to metric and other units. For example, a micrometer (µm) is $10^{-6}$; a picoliter (pl) is $10^{-12}$; and a kilogram (kg) is $10^{3}$ grams. Also applied to seconds, units, mols, hertz, volts, farads, ohms, curies, equivalents, osmols etc. Combinations of prefixes are no longer allowed, so that *n* is used instead of mµ and *p* instead of µµ.

† Formerly called *micron*, with the same abbreviation *i.e.*, µ. A micron is a unit of measurement of length or distance.

$$1\mu = 0.001 \text{ mm} = 0.000039 \text{ in.}$$

## D. Non-SI Units

Although the SI system of units is coming into use the world over, there are a few recommended non-SI units which are still frequently used (Table 4). However, these will be abandoned in time but probably not until after the useful life of this text.

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**Table 4. Non-SI Units still in use**

| S.N. | Unit | Symbol | Definition |
|---|---|---|---|
| 1. | Angstrom* | Å | $10^{-10}$ m; 10–8 cm ; $10^{-7}$ mm; $10^{-4}$ µ |
| 2. | Atmosphere | atm | 760 mm Hg |
| 3. | Calorie *a.* international | $cal_{IT}$ | 4.1868 J |
| | *b.* thermochemical | cal | 4.184 J |
| 4. | Dyne | dyn | $10^{-5}$ N |
| 5. | Erg | erg | $10^{-7}$ J |
| 6. | Gauss | G | $10^{-4}$ T (testa) = $Vsm^{-2}$ (volt) |
| 7. | Litre | l | $10^{-3}$ $m^3$ = $dm^3$ |
| 8. | Micron | µ | $10^{-6}$ m = µm |
| 9. | Millimicron | mµ | $10^{-9}$ m = nm |

* No longer used, nanometer used instead.

## E. Units Used in Conjunction with SI

The principal changes relevant to physiology and medicine are as follows :

1. *Litre* (*l*). The unit of volume is the cube metre ($m^3$), but since this is too large a unit for practical use, the cubic decimetre ($dm^3$) is frequently used. An alternative name for the cubic decimetre is the litre. A litre is the volume occupied by one kilogram of pure water at 4°C under a presence of 760 mm of mercury.

$$1 \text{ litre} = 1 \text{ dm}^3 = 10^{-3} \text{ m}^3$$
$$1 \text{ millilitre} = 1 \text{ cm}^3 = 10^{-6} \text{ m}^3$$
$$1 \text{ microlitre} = 1 \text{ mm}^3 = 10^{-9} \text{ m}^3$$

The terms millilitre and microlitre will, however, be abandoned in time.

2. *Gram* (*g*). The basic units of mass is the kilogram, but the gram is used as an elementary unit and also in association with prefixes (µg, mg) until a name is adopted for the basic unit of mass.

3. *Minute, hour and year*. The basic SI unit of time is the second but the common units of time such as minute, hour and year are frequently used for convenience.

4. *Kilopascal* (*kPa*). Pressure is the force exerted, divided by the area over which it acts. In SI units, the basic unit of pressure is the newton per square metre ($N/m^2$ or $Nm^{-2}$). It is this unit that is also known as the pascal (Pa). The pascal is too small a pressure for use in clinical medicine and the unit of 1,000 pascals or kilopascal (kPa) is, therefore, used. The relationship between the kilopascal and mm Hg is that :

$$1 \text{ kPa} = 7.5 \text{ mm Hg}$$
$$0.133 \text{ kPa} = 1 \text{ mm Hg}$$

Since blood pressure is usually measured using a mercury manometer, it seems likely that blood pressure will continue to be expressed in mm Hg for many years to come.

Central venous pressures are frequently measured in centimetres of water. The conversion of kilopascals is :

$$10 \text{ cm of water} = 1 \text{ kPa}$$

5. *Kilojoule* (*kJ*). The unit of heat and energy that has been used in nutrition is the Calorie (kilocalorie). This is the amount of heat required to raise 1 kilogram of water 1°C. But this does not form part of the SI units system.

The work done when the force of one newton acts through a distance of one metre is termed the joule (J). This is also the work done when one ampere of electricity flows through a resistance of one ohm for one second. One joule per second is, thus, equal to one watt. The joule has been adopted as the unit of both heat and energy in the SI units system. Like the pascal, it is too small a unit for clinical use and the kilojoule (kJ), corresponding to 1,000 joules and the megajoule (MJ), corresponding the 1,000,000 joules are therefore used.

The conversion from Calories to kilojoules is :

$$1 \text{ Calorie} = 4.2 \text{ kJ}$$

6. *Millimoles per litre.* The concentration of a substance in body fluids is expressed in *millimoles per litre* (instead of g/100 ml) provided that its molecular weight is known. When the molecular weight cannot be acurately determined in the case of the plasma proteins), concentrations are expressed in *grams per litre*.

## F. Definition of Standards and Equivalents

| *Standard* | *Abbreviation* | *Equivalent* |
|---|---|---|
| Meter | m | 1,650,763.73 wavelengths in vacuo of the unpertured transition $2p_{10}$ -$5d_5$ in $Kr^{86}$ |
| Kilogram | kg | mass of the international kilogram at sevres, France |
| Second | sec | 9, 192, 631, 770 vibrations of the unper turbed hyperfine transition 4, 0–3, 0 of the fundamental state $^2S_{1/2}$ in $Cs^{133}$* |
| Thermochemical calorie | cal | 4.1840 joules |
| Litre | 1 | 0.001, 000, 028 $meter^3$ |
| Inch | in. | 0.0254 meter |
| Pound (avdp.) | 1b | 0.453, 592, 37 kg |

* There is no measurable difference between this and the previous standard of time, 1/31, 556, 925. 9747 of the tropical year at $12^h$ ET, 0 January 1990. For this reason and because even more accurate maser standards may soon be available, the Cs standard was adopted provisionally rather than "permanently".

# HINTS FOR USING THE METRIC SYSTEM

1. The metric system uses symbols rather than abbreviations. Hence, do not place a period (or full stop) after metric symbols (*e.g.*, 1 g, not 1 g.). Use a period after a symbol only at the end of a sentence, but always use a period with the symbol for inches (in.)
2. Metric symbols are always singular; they do not have a plural form (*e.g.*, 20 km, not 20 kms).
3. Capital initial letters are never used for units, except when named after famous scientists, such as N (Newton), J (Joule) and W (Watt).
4. Do not mix units or symbols (*e.g.*, 5.3 m, not 5 m 300 mm).
5. Symbols combined in a quotient can be written as, for example, metre per second or $ms^{-1}$. The use of the solidus (strope, /) is restricted to indicating the unit of a variable, such as temperature /ºC.
6. Except for degree Celsius, always leave a space between a number and a metric symbol (*e.g.*, 70 mm, not 70mm; 10°C, not 10° C).
7. The comma is no longer used to separate groups of 3 digits, but a space is left instead (*e.g.*, 236 892 714 not as 236,892,714.
8. The raised decimal point is not correct. The internationally-accepted decimal sign is placed level with the feet of the numeral (*e.g.*, 3.182, not 3·182).
9. Express measurements in units that require only a few decimal places. For example, 0.4 m is more easily manipulated and understood than 400,000,000 nm.
10. Familiarize yourself with manipulations within the metric system. Work within one system, and do not convert back and forth between the metric and English (or the old c.g.s.) systems.
11. Use a zero before a decimal point when the number is less than one (*e.g.*, 0.35 m, not .25 m)
12. When measuring water, the metric system offers an easy and common conversion from volume measured in litres to volume measured in cubic metres to mass measured in grams : 1 ml = 1 $cm^3$ = 1 g.

# APPENDIX V

## COMPARISON OF METRIC AND OTHER UNITS

### Units of Length

| | | | |
|---|---|---|---|
| 1 centimetre | = 0.3937 inch | 1 inch | = 2.5400 centimetres |
| 1 mitre | = 3.2808 feet | 1 foot | = 0.30480 metre |
| 1 metre | = 1.09361 yards | 1 yard | = 0.91440 metre |
| 1 kilometre | = 0.62137 mile | 1 mile | = 1.60934 kilometres |

### Units of Area

| | | | |
|---|---|---|---|
| 1 square cm | = 0.1550 sq. in. | 1 square in. | = 6.4516 sq. cm. |
| 1 square metre | = 10.7638 sq. ft. | 1 square ft. | = 0.9290 sq. m. |
| 1 square metre | = 1.1960 sq. yds. | 1 square yd. | = 0.83613 sq. m. |
| 1 square km. | = 0.38610 sq. mile | 1 square mile | = 2.5900 sq. km. |
| 1 hectare | = 2.47105 acres | 1 acre | = 0.40469 hectare |

### Units of Volume

| | | | |
|---|---|---|---|
| 1 cubic cm. (c.c.) | = 0.061024 cubic in. | 1 cubic in. | = 16.387 c.c. |
| 1 cubic m. | = 35.3144 cubic ft. | 1 cubic ft. | = 0.028317 cubic m. |
| 1 cubic m. | = 1.3079 cubic yds. | 1 cubic yd. | = 0.7645 cubic m. |

### Measures of Liquid Capacity

*British Units (or Imperial Units)*

pennyweight = 3.858 carats
1 gallon = 4 quarts = 8 pints = 32 gills
1 gallon = 4.54596 litres
1 litre = 0.2200 gallon = 1.7598 pints

*U.S. Units*

1 gallon = 4 quarts = 8 pints = 32 gills
1 gallon = 3.78533 litres
1 litre = 0.26418 gallon = 2.1134 pints

*Apothecaries' Units (British)*

1 gallon = 8 pints = 160 fluid ounces
1 fluid ounce = 8 fluid drachms = 24 scruples = 480 minims
1 gallon = 4.54596 litres
1 litre = 0.2200 gallon = 35.196 fluid ounces

*Apothecaries' Units (U.S.)*

1 gallon = 8 pints = 128 fulid ounces
1 fluid ounce = 8 fluid drachms = 480 minims
1 gallon = 3.78533 litres
1 litre = 0.26418 gallon = 33.81504 fluid ounces

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## Units of Mass

***Avoirdupois Weight.*** This is a British and American system of weights, based on a pound of 16 ounces.

| | | |
|---|---|---|
| 1 hundredweight | = | 4 quarters = 8 stones = 112 pounds |
| 1 pound | = | 16 ounces = 256 drachms = 7,000 grains |
| 1 grain | = | 0.064799 g |
| 1 grain | = | 15.4323 grains |
| 1 hundredweight | = | 50.80238 kg |
| 1 kilogram | = | 0.0198461 hundredweight |
| 1 millier | = | 1 metric ton = 10 quintals |
| 1 quintal | = | 10 myriagram = 100 kilogram = 0.09842059 ton |
| 1 kilogram | = | 2.204621 pounds |
| 1 pounds | = | 0.4535926 kilogram |

***Troy Weight.*** This is a system of weights, used for gems and precious metals (gold, silver) and also for drugs.

| | | |
|---|---|---|
| 1 pound | = | 12 ounces = 240 pennyweights |
| 1 pennyweight (dwt.) | = | 6 carats = 24 grains |
| 1 gram | = | 0.3215 ounce = 0.643 pennyweight = 3.858 carats |
| 1 carats | = | 0.25920 gram |
| *Apothecaries's Weight* | – | This is a system of weights, used in pharmacy. |
| 1 pound | = | 12 ounces = 96 drachms |
| 1 drachm | = | 3 scruples = 60 grains |
| 1 gram | = | 0.03215 ounce = 0.2572 drachm = 0.7716 scruple |
| 1 scurple | = | 1.29598 gram |

**Carat :** (1) A measure of weight of *diamonds* and other gems. (2) A measure of fineness of *gold*, expressed as parts of gold in 24 parts of the alloy. Thus, 24 carat gold is pure gold, 18 carat gold contains 18 parts in 24 or has a fineness of 750.

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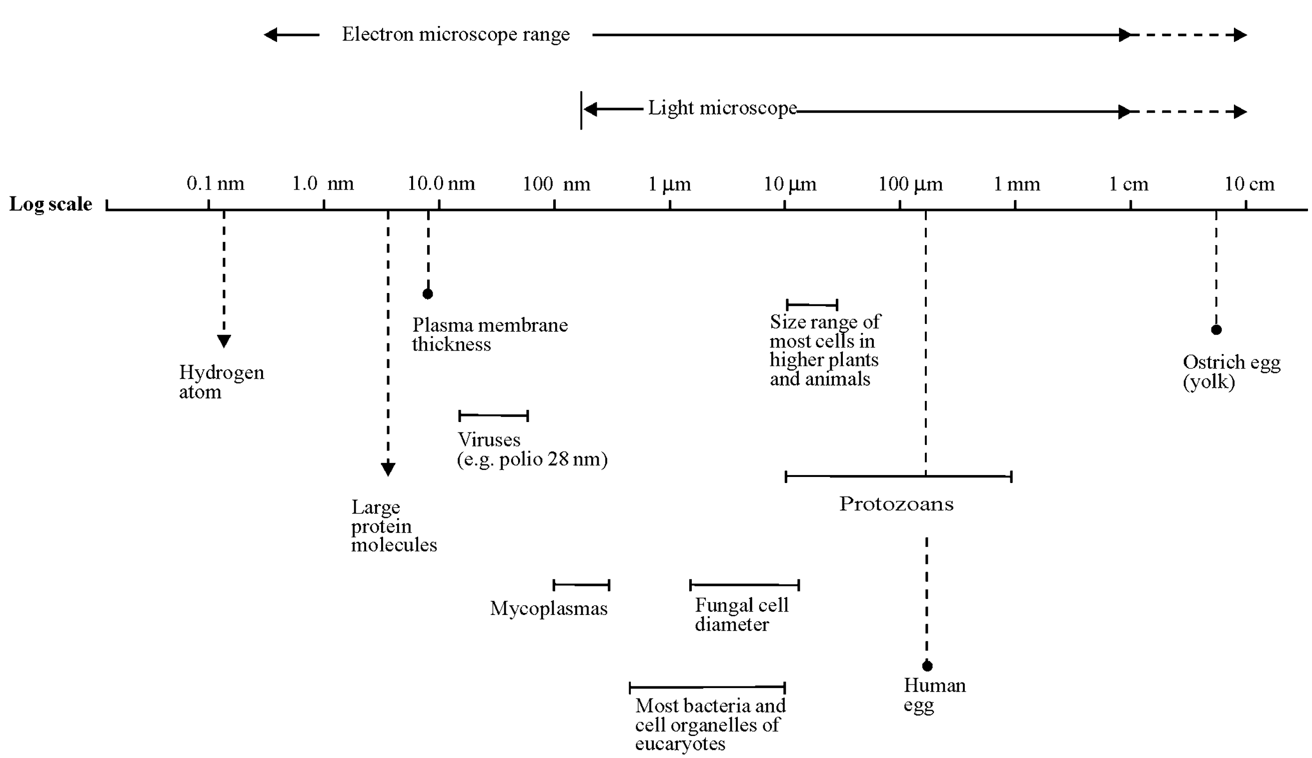
# APPENDIX VI

## Mathematical Signs and Symbols

| | |
|---|---|
| $=$ | equals |
| $\backsimeq$, $\cong$ | equals approximately |
| $\neq$ | is not equal to |
| $\equiv$ | is identical to, is defined as |
| $>$ | is greater than |
| » | is much greater than |
| $<$ | is less than |
| « | is much less than |
| $\geqq$, $\geq$ | is more than or equal to (or, is no less than) |
| $\leqq$, $\leq$ | is less than or equal to (or, is no more than) |
| $\pm$ | plus or mimus (*e.g.*, $\sqrt{4} = +2$) |
| $\propto$ | is proportional to (*e.g.*, Hooke's law : $F \propto x$, or $F = -kx$ |
| $\Sigma$ | the sum of |
| $\bar{x}$ | the average value of x |

# APPENDIX VII

## Relative Sizes of Structures, from Atom to Eggs



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# APPENDIX VIII

## LIST OF ABBREVIATIONS AND SYMBOLS

The abbreviations are used to conserve space. They have become a part of the nomenclature of modern biochemistry. These are used in the current biochemical literature to such an extent that some publications are rendered unintelligible by the numerous abbreviations. They should, henceforth, be used cautiously. The abbreviations are justifiably used in the case of high molecular weight compounds (such as **proteins**) where the individual components are indicated by such symbols. The monomers are abbreviated by lowercase letters. The abbreviations of **metabolites** are mostly superfluous. *The names of the enzymes should never be abbreviated*. Although the use of abbreviations, in general, should be discouraged, they have their own value and are, therefore, listed here as a useful reference.

### 1. CARBOHYDRATES

| | |
|---|---|
| Abe | Abequose |
| Ara | Arabinose |
| Fru | Fructose |
| Fru-1-P, F1P | Fructose-1-phosphate |
| Fru-6-P, F6P | Fructose-6-phosphate |
| Fru-1-P, 6-P, FDP | Fructose-1, 6-diphosphate |
| Gal | Galactose |
| GalN | D-galactosamine |
| GalNAc | *N*-acetyl-D-galactosamine |
| Glc | Glucose |
| GlcA | Gluconic acid |
| GlcN | D-glucosamine |
| GlcN Ac, NAG | *N*-acetyl-D-glucosamine |
| Glc-1-P, G1P | Glucose-1-phospahate |
| Glc-6-P, G6P | Glucose-6-phosphate |
| GluUA | Glucuronic acid |
| IdoUA | Iduronic acid |
| Mal | Maltose |
| Man | Mannose |
| Mur | Muramic acid |
| MurNAc, NAM | N-acetyl-muramic acid |
| Neu | Neuraminate |
| NeuNAc, NAN | *N*-acetyl-D-neuraminaic acid |
| Rib | Ribose |
| dRib | Deoxyribose |
| Rul | Ribulose |
| Sia | Sialic acid |
| Xul | Xylulose |
| Xyl | Xylose |

**Glucose** may not be abbreviated as Glu since this symbol is already reserved for an amino acid, glutamic acid. Also, the symbol G cannot be used for glucose since this is often used to denote a nitrogenous base, guanine in the nucleic acids.

Contents



## 2. AMINO ACIDS

**Three-letter abbreviations** are used in text books to designate amino acid residues in peptide sequences but *not to designate free amino acids*. **One-letter symbols** were devised for computer storage and retrieval of sequence date but are also being used for tabulation of long sequences.

| Three-letter abbreviation† | One-letter ‡ | Amin acid |
|---|---|---|
| Ala | A | Alanine |
| Arg | R | Arginine |
| Asn, Asp-NH*$_2$] Asx | N ] B | Asparagine |
| Asp | D | Aspartic acid |
| Cys, Cys-SH* | C | Cysteine |
| Gln, Glu-NH*$_2$] Glx | Q ] Z | Glutamine |
| Glu | E | Glutamic acid |
| Gly | G | Glycine |
| His | H | Histidine |
| Ile | I | Isoleucine |
| Leu | L | Leucine |
| Lys | K | Lysine |
| Met | M | Methionine |
| Phe | F | Phenylalanine |
| Pro | P | Proline |
| Ser | S | Serine |
| Thr | T | Threonine |
| Trp | W | Tryptophan |
| Tyr | Y | Tyrosine |
| Val | V | Valine |

† Note that the abbreeviations for amino acids are the first letters of their names except typtophan (Trp), isoleucine (IIe), asparagine (Ans) and glutamine (Gln).

‡ Also note that barring 4 letters (J, O, U, X), all the remaining 22 letters of English alphabet have been utilized in giving one-letter symbol to the standard amino acids. The symbols for the small amino acids are the first letters of their names (*e.g.*, A for alanine, G for glycine and L for leucine); the other symbole have been agreed upon by convention.

* Not preferred

The 3-letter abbreviations for the **derivatives of amino acids** are:

| | |
|---|---|
| Cys-SO$_3$H | Cysteic acid |
| Cys-S-S-Cys | Cystine |
| fMet | N-formylmethionine |
| Hyl | Hydroxylysine |
| Hyp | Hydroxyproline |
| Pgl, pGlu | Pyroglutamic acid |

## 3. PROTEINS

| | |
|---|---|
| ABC | Acyl carrier protein |
| CBG | Corticosteroid-binding globulin |

| | |
|---|---|
| GSH | Glutathione (reduced form) |
| GSSG | Glutathione (oxidized form) |
| Hb | Hemoglobin (deoxygenated) |
| HbA | Adult hemoglobin |
| HbCO | CO hemoglobin |
| HbF | Fetal hemoglobin |
| $HbO_2$ | Oxyhemoglobin |
| HDL | High density lipoprotein |
| IDL | Intermediate density lipoprotein |
| IF | Interferon |
| $IP_3$ | Inositol triphosphate |
| ITP | Inosine triphosphate |
| LDL | Low density lipoprotein |
| Mb | Myoglobin (deoxygenated) |
| MbCO | CO myoglobin |
| $MbO_2$ | Oxymyoglobin |
| Met Mb | Methemyoglobin |
| NHI | Nonheme iron protein |
| RBP | Retinol-binding protein |
| TBG | Thyroxine-bnding globulin |
| VHDL | Very high density lipoprotein |
| VLDL | Very low density lipoprotein |

## 4. LIPIDS

| | |
|---|---|
| Cer | Ceramide |
| EFA | Essential fatty acids (refer to linoleic, linolenic and arachi donic acids) |
| FA | Fatty acid |
| FFA | Unesterified free fatty acid (same as NEFA) |
| HCC | 25-hydroxycholecalciferol, an active metabolite of vitamin $D_3$ |
| NEFA | Unesterified ( = non-esterified) free fatty acid (same as FFA) |

## 5. NUCLEIC ACIDS AND RELATED COMPOUNDS

### A. Nitrogenous bases

| | |
|---|---|
| A, Ade | Adenine |
| B | 5-bromouracil |
| C, Cyt | Cytosine |
| G, Gua | Guanine |
| MC | Methylcytosine |
| T, Thy | Thymine |
| U, Ura | Uracil |

### B. Nitrogenous base derivatives

| | |
|---|---|
| DiHu | 5, 6-dihydrouracil |
| DiMeA | 6-dimethyladenine |
| 2-DiMeG | 2-dimethylguanine |
| HMC | 5-hydroxymethylcytosine |
| 6-IPA | 6-N-isopentenyladenine |
| 6-MeA | 6-methyladenine |
| 5-MeC | 5-methylcytosine |

| | |
|---|---|
| 1-MeG | 1-methylguanine |
| 4-ThioU | 4-thiouracil |
| Ψ,ψU | Pseudouridine |

## C. Nucleosides

| *Abbreviations** | *Systemic name* | *Trivial name* |
|---|---|---|
| **Ribonucleosides** | | |
| AR, Ado | Adenine ribonucleoside | Adenosine |
| CR, Cyd | Cytosine ribonucleoside | Cytidine |
| GR, Guo | Guanine ribonucleoside | Guanosine |
| TR, Thd | Thymine ribonucleoside | Thymidine |
| UR, Urd | Uracil ribonucleoside | Uridine |
| **Deoxyribonucleosides** | | |
| AdR | Adenine deoxyribonucleoside | Deoxyadenosine |
| CdR | Cytosine deoxyribonucleoside | Deoxycytidine |
| GdR | Guanine deoxyribonucleoside | Deoxyguanosine |
| TdR | Thymine deoxyribonucleoside | Deoxythymidine |
| UdR | Uracil deoxyribonucleoside | Deoxyuridine |

* In the case of ribonucleosides, the second set of abbreviations is preferred.

## D. Nucleoside phosphates ( = nucleotides)

| *Nucleosides* | | *Abbreviations for nucleotides** | | |
|---|---|---|---|---|
| *Name* | *Abbreviation*† | *Monophosphate* | *Diphosphate* | *Triphosphate* |
| Adenosine | A, Ado | AMP | ADP | ATP |
| Cytidine | C, Cyd | CMP | CDP | CTP |
| Guanosine | G, Guo | GMP | GDP | GTP |
| Inosine | I, Ino | IMP | IDP | ITP |
| Thymidine | T, Thd | TMP | TDP | TTP |
| Uridine | U, Urd | UMP | UDP | UTP |

* These abbreviations are used for 5′-mono-5′-di-and 5′-triphosphates. The 3′-phosphates are, however, denoted by a number; for example, adenosine -3’-monophosphate is abbreviated as 3’-AMP or Ado-3’-P, adenosine 3′-triphosphate as 3′-ATP or Ado-3′ $P_3$.

† The first set of abbreviations is used to describe the long sequence in oligonucleotides. These letters are, otherwise, reserved for the nitrogenous bases.

## E. Related compounds

| | |
|---|---|
| DHU, $UH_2$ | Dihydrouridine |
| DNA | Deoxyribonucleic acid |
| cDNA | Complementary DNA |
| mDNA | Inosine |
| MtDNA | Mitochondrial DNA |
| RNA | Ribonucleic acid |
| hnRNA | Heterogeneous nuclear RNA |

| | |
|---|---|
| mRNA | Messenger RNA or template RNA |
| nRNA | Ribosomal RNA |
| ns | Nucleoside(s) |
| nt | Nucleotide (s) |
| R | Purine nucleoside |
| rRNA | Ribosomal RNA |
| sRNA | Soluble RNA (now replaced by tRNA) |
| tRNA | Transfer RNA (formerly called as sRNA) |
| X | Any nucleoside |
| Y | Pyrimidine nucleoside |

For the coining of the abbreviation 'ns', see footnote on page 287.

## 6. ENZYMES

| | |
|---|---|
| ADH | Alcohol dehydrogenase |
| ATCase | Aspartate transcarbamoylase |
| ATPase | Adenosine triphosphatase |
| Bio | Biotin |
| ChAT | Choline acetyltransferase |
| ChE | Cholinesterase |
| CPK, CK | Creatine phosphokinase |
| DNase | Deoxyribonuclease |
| E, Enz | Enzyme |
| EC (followed by numbers) | Enzyme commission number (IUB system) |
| EF | Elongation factor |
| eu | enzyme unit |
| FSH | Fibrin-stabilizing factor (or fibrinase) |
| GDH | Glutamic dehydrogenase |
| GOT | Glutamate-oxaloacetate transaminase |
| HIOMT | Hydroxyindole-o-methyl transferase |
| IF | Initiation factor |
| LDH | Lactate dehydrogenase |
| MDH | Malate dehydrogenase |
| PABA | p-aminobenzoic acid |
| PFK | Phosphofructokinase |
| RF | Releasing factor |
| RNase | Ribonuclease |
| SRP | Signal recognition particle |

## 7. COENZYMES

| | |
|---|---|
| Acetyl-CoA | Acetyl-coenzyme A |
| Acyl-CoA | General symbol for an organic compound. coenzyme A ester |
| CoA | Coenzyme A ("A" stands for acyl activation), used in names of compounds |

| | |
|---|---|
| CoA-SH | Coenzyme A, used in reactions |
| CoF | Coenzyme F ('F" stands for formyl and formaldehyde activation) |
| CoQ | Coenzyme Q (now replaced by Q) |
| DHFA, $FH_2$ | Dihydrofolic acid |
| $DPN^+$ | Diphosphopyridine nucleotide (oxidized form), now replaced by $NAD^+$ |
| DPNH | Diphosphopyridine nucleotide (reduced form), now replaced by NADH |
| DPT | Diphosphothiamine (same as TPP) |
| FAD | Flavin adenine dinucleotide (oxidized form) |
| $FADH_2$ | Flavin adenine dinucleotide (reduced form) |
| FMN | Flavin mononucleotide (oxidized form) |
| $FMNH_2$ | Flavin mononucleotide (oxidized form) |
| HS-CoA | Reduced coenzyme A |
| LIP ($S_2$) | Lipoic acid |
| LTPP | Lipothiamide pyrophosphate |
| $NAD^+$ | Nicotinamide adenine dinucleotide (oxidized form), formerly called as $DPN^+$ or coenzyme I or coezymase |
| NADH | Nicotinamide adenine dinucleotide (reduced form), formerly called as DPNH |
| $NADP^+$ | Nicotinamide adenine dinucleotide phosphate (oxidized form), formerly called as $TPN^+$ or coenzyme II |
| NADPH | Nicotinamide adenine dinucleotide phosphate (reduced form), formerly called as TPNH |
| PAL, PL | Pyridoxal |
| PALP, PLP | Pyridoxal phosphate |
| PAMP | Pyridoxamine phosphate |
| PEP | Phosphoenolpyruvate |
| Q, UQ | Ubiquinone (formerly called as CoQ) |
| THFA, $FH_4$ | Tetrahydrofolic acid |
| $TPN^+$ | Triphosphopyridine nucleotide (oxidized form), now replaced by $NADP^+$ |
| TPNH | Triphosphopyridine neucleotide (reduced form), now replaced by NADPH |
| TPP, ThPP | Thiamine pyrophosphate (same as DPT) ; formerly called as cocarboxylase |
| UDP | Uridine diphosphate |

## 8. ANIMAL HORMONES

| | |
|---|---|
| ACTH | Adrenocorticotrophic hormone ( = corticotropin) |
| ADH | Antidiuretic hormone ( = vasopressin) |
| cAMP | Adenosine 3', 5'-cyclic monophosphate ( = 3', 5'-adenylic acid) |

Contents



| | |
|---|---|
| CCK | Cholecystokinin |
| cGMP | Guanosine 3', 5'-cyclic monophosphate |
| Compound A | 11-dehydrocorticosterone |
| Compound B | Corticosterone |
| Compound E | Cortisone |
| Compound F | Cortisol |
| Compound S | 11-deoxycortisol |
| CRF | Corticotropin-releasing factor |
| CT | Calcitonin (same as TCT) |
| DEA, DHEA | Dehydroepiandrosterone |
| DHT | Dihydrotestosterone |
| DOC | Deoxycorticosterone |
| DOCA | Deoxycorticosterone acetate |
| ESF | Erythrocyte stimulating factor ( = erythropoietin) |
| FSH | Follicle-stimulating hormone ( = follitropin) |
| FSH-RF | Follicle-stimulating hormone-releasing factor |
| GH | Growth hormone (same as STH) |
| GH-RF | Growth hormone-releasing factor |
| GSS | Gonad-stimumating substance (in echinoderms) |
| GTH | Gonadotrophic hormones ( = gonadotropins) |
| HCG | Human chorionic gonadotropin |
| HCS | Human chorionic somammotropin (same as HPL) |
| hG-factor | Hypoglycemic factor (*i.e.*, insulin) |
| HG-factor | Hyperglycemic factor (*i.e.*, glucagon) |
| HPL | Human placental lactogen (same as HCS) |
| 5-HT | 5-hydroxytryptamine (*i.e.*, serotonin) |
| ICSH | Interestitial cell-stimulating hormone (same as LH) |
| In | insulin |
| JH | Juvenile hormone (same as SQH) |
| LH | Luteinizing hormone (same as ICSH) |
| LH-RF | Luteinizing hormone-releasing factor |
| LTH | Luteotrophic hormone (same as MH or PL) |
| MH | Mammotrophic hormone (same as LTH or PL) ; also moulting hormone (same as PGH) |
| MIS | Maturation-inducing (in echinoderms) |
| MRF | Melanocyte-stimulating hormone-releasing factor |
| MSH | Melanocyte-stimulating hormone |
| PG | Prostaglandin |
| PGH | Prothoracic gland hormone ( = ecdysone) |
| PL | Prolactin (same as LTH or MH) |
| PRF | Prolactin-releasing factor |
| PTH | Parathormone ( = Collip's hormone) |

For the coining of the abbreviation, hG-factor, see footnote on page 862.

| | |
|---|---|
| PZ | Pancreozymin |
| REF | Renal erythropoietic factor |
| SQH | Status quo hormone (same as JH) |
| STH | Sometotrophic hormone or somatotropin (same as GH) |
| TCT | Thyrocalacitonin (same as CT) |
| Thx, $T_4$ | Thyroxine ( = 3, 5, 3', 5'-tetraiodothyronine) |
| TIT, $T_3$ | 3, 5, 3'-triiodothyronine |
| TRF | Thyrotropin-releasing factor |
| TSH | Thyroid stimulating hormone ( = thyrotropin) |
| URF | Uterine-relaxing factor ( = relaxin) |
| VP | Vasopressin |

## 9. PLANT HORMONES

| | |
|---|---|
| ABA | Abscisic acid |
| AE | Avena Einheit |
| CCC | Chlorocholine chloride |
| 2, 4-D | 2, 4-dichlorophenoxyacetic acid |
| ETH | Ethylene |
| GA | Gibberellic acid |
| IAA | Indole-3-acetic acid |
| IAc | Indoleacetaldehyde |
| IBA | Indolebutyric acid |
| IPA | Indole-3-propionic acid |
| IPyA | Indole-3-pyruvic acid |
| K | Kinetin ( = 6-furfurylaminopurine) |
| NAA | 1-naphthaleneacetic acid |
| NAd | 1-naphthalene acetamide |
| NOA | 2-naphthoxyacetic acid |
| PAA | Phenyl acetic acid |
| POA | Phenoxyacetic acid |
| 2, 4, 5-T | 2, 4, 5-trichlorophenoxyacetic acid |

## 10. VITAMINS

| | |
|---|---|
| APA factor | Antipernicious anemia factor |
| CR | Citrivorum factor |
| DHF, FH2 | Dihydrofolate (or $H_2$ folate) |
| FA | Folic acid (same as PGA) |
| LA | Lipoic acid |
| PGA | Pteroyl-L-glutamic acid (same as FA) |

Contents



| | |
|---|---|
| PABA | Para-aminobenzoic acid |
| POF | Pyruvate oxidation factor, refers to α-lipoic acid |
| SLR factor | Streptococcus lactis R factor |
| THF, $FH_4$ | Tetrahydrofolate (or $H_4$ folate) |
| Vitamin $A_1$ | Retinol |
| " $A_2$ | 3-dehydroretinol |
| " $B_1$ | Thiamine |
| " $B_2$ | Riboflavin |
| " $B_3$ | Pantothenic acid |
| " $B_5$ | Niacin |
| " $B_6$ | Pyridoxine |
| " $B_7$ | Biotin |
| " $B_9$ | Folacin |
| " $B_{12a}$ | Cyanocobalamin |
| " $B_{12b}$ | Hydroxocobalamin |
| " $B_{12c}$ | Nitrocobalamin |
| " C | Ascorbic acid |
| " $D_2$ | Ergocalciferol |
| " $D_3$ | Cholecalciferol |
| " E | Tocopherol |
| " $K_1$ | Phylloquinone |
| " $K_2$ | Farnoquinone |
| 1,25 $(OH)_2D_3$ | 1, 25-dihydroxycholecalciferol |

## 11. MISCELLANEOUS

| | |
|---|---|
| A | Ampere |
| A | Absorbance |
| AA | Amino acid |
| Å | Angström units(s), $10^{-10}$m, 0.1 nm |
| $A^-$ | General symbol for anion |
| a | atto, a prefix denoting one million millionth, *i.e.*, $10^{-18}$ |
| Ab | Absorbance |
| atm | Atmosphere : 1 atm = 760 torr = mean atomspheric pressure at sea level |
| ACH, ACh | Acetylcholine |
| AIDS | Acquired immuno deficiency syndrome |

| | |
|---|---|
| AT-10 | Dehydrotachysterol ( = antitetany compound 10) |
| BMR | Basal metabolic rate |
| BOH | General symbol for an alkali |
| bp | Base pair |
| C | centigrade |
| c | centi, a prefix denoting one hundredth, *i.e.*, $10^{-2}$ |
| Cal | 1,000 calories ; kilocalorie |
| cal | calorie (gram calorie) |
| cap | Capillary |
| cc | cubic centimetres |
| cer | Ceramide |
| Ci | curie |
| Chl | Chlorophyll |
| CM-cellulose | o-(carboxymethyl) cellulose |
| CNS | Central nervous system |
| conc. | Concentration |
| cpm | counts per minute |
| cps | cycles per second (same as Hz) |
| Cr | Creatinine |
| CrP | Creatinine phosphate |
| cyt | cytochrome |
| D | Geometric isomer of L form of chemical compound |
| *D* | Diffusion Coefficient |
| *d* | diem, day(s) |
| d | 2′-deoxyribo- |
| *d* | density |
| DEAE-Cellulose | o-(diethylaminoethyl) cellulose |
| DFP | Diisoprpyl fluorophosphate |
| DHAP | Dihydroxyacetove phosphate |
| DIT | Diiodotyrosine (same as $I_2$tyr) |
| DNFB | Dinitrofluorobenzene (same as FDNB) |
| DNP | 2, 4-dinotrophenol |
| Dol | Dolichol |
| DOPA, dopa | 3, 4-dihydroxyphenylalaline |
| dps | disintegrations per second |
| DPT | Diphosphothiamine |
| E | Electrical potential |
| e, $e^-$ | Electron |
| Ea | Energy of activation |
| EDTA | Ethylenediminetetraacetic, acid, a reagent used to chelate divalent metals |
| ELISA | Enzyme-linked immunosorbent assay |
| EM | Electron microscopy |
| ER | Endoplasmic reticulum |
| ETS | Electron transport system |

| | |
|---|---|
| Eq | Equivalent(s) ; also equation |
| F | Female |
| F | Fahrenheit |
| *f* | Frictional coefficient |
| F | Fatty acid |
| Fd | Ferredoxin |
| FDA | Food and Drug Administration |
| FDNB | Fluorodinitrobenzane (same as DNFB) |
| FP | Flavoprotein |
| FSF | Fibrin-stabilizing factor |
| g, gm | grams (s) |
| *g* | unit of force, 1 *g* is equal to the force of gravity on the earth's surface |
| G | giga, a prefix denoting thousand million, $10^9$ (American) or million million, $10^{12}$ (British) |
| GABA | γ-aminobutyric acid |
| GLC | Gas liquid chromatography |
| G3P, GAP | Glyceraldehyde-3-phospahte |
| GSC | Gas solid chromatography |
| $^3H$ | Tritium |
| h, hr | Hour |
| HA | General symbol for an acid |
| Hb | Hemoglobin |
| HIV | Human immuno deficiency virus |
| HPLC | High-performance liquid chromatography |
| Hz | Hertz, unit of frequency : 1 cycle per second = 1 hertz |
| IEP, pl | Isolectric point |
| Ig | Immunoglobulin |
| IgG | Immunoglobulin G |
| INH | Isonicotinic acid hydrazide ( = isoniazid) |
| IR | Infrared light |
| Ityr | Monoiodotyrosine (same at MIT) |
| $I_2$tyr | Diiodotyrosine ( same as DIT) |
| IUB | International Union of Biochemistry |
| K | Dissociaton constant |
| $K_a$ | Acid dissociation constant |
| k | Kilo, a prefix denoting thousand, *i.e.*, $10^3$ |
| *k* | rate constant |
| kb | kilobase |
| kbp | kilobase pair |
| kcal (Cal) | Kilocalorie (1,000 calories) |
| kD | kilo Dalton |
| Keq | Equilibrium constant |
| αKG | α-ketoglutarate |
| $K_i$ | Inhibitor constant |

Contents



| | |
|---|---|
| $K_m$ | Michaelis constant (substrate concentration producing half-maximal velocity) |
| L | Litre |
| L | Geometric isomer of D form of chemical compound |
| LATS | Long-acting thyroid stimulator, now replaced by TSI |
| log | Logarithm to the base 10 |
| LSD | Lysergic acid diethylamide |
| M | Male |
| M | Molarity (mols/litre) |
| *M* | mega, a prefix denoting million, *i.e.*, thousand thousand or $10^6$ |
| m | milli, a prefix denoting one thousandth or $10^{-3}$ ; also metre(s) |
| mev | million electron volt |
| MI | Myocardial in fraction |
| min | minute(s) |
| MIT | Monoiodotyrosine (same as Ityr) |
| mm Hg | Millimeters of mercury |
| mo | Month(s) |
| mol | Mole |
| MW, mol wt | Molecular weight |
| N | Normality (of a solution) |
| n | nano, a prefix denoting one billionth, *i.e.*, one thousand millionth or $10^{-9}$ |
| NDP | Any nucleoside diphosphate |
| nm | nanometer ($10^{-9}$ metre) |
| NMR | Nuclear magnetic resonance |
| NPN | Nonprotein nitrogen |
| NTP | Any nucleoside triphosphate |
| OAA | Oxaloacetate |
| OD | Optical density |
| P | Phosphate (radical) |
| *P* | Pressure |
| p | pico, a prefix denoting one trillionth, *i.e.*, one thousand billionth or $10^{-12}$ |
| ~ P | High-energy phosphate |
| Pa | Pascal |
| PAGE | Polyacrylamide gel electrophoresis |
| PC, PPC | Paper partition chromatography |
| PEP | Phosphoenolpyruvate |
| PCr | Phosphocreatine |
| 2PG | 2-phosphoglycerate |
| 3PG | 3-phosphoglycerate |
| pH, *p*H | Negative logarithm of the hydrogen ion concentration of a solution |

| | |
|---|---|
| $P_i$ | Inorganic phosphate |
| *p*K | Negative logarithm of the equilibrium constant for a chemical reaction |
| $pO_2$ | Partial pressure of oxygen |
| PP, $PP_i$ | Inorganic pyrophosphate |
| $PP...P_i$ | Inorganic polyphosphates |
| PQ | Plastoquinone (same as Q) |
| PRPP | 5-phosphoribosyl 1-pyrophosphate |
| Q | Ubiquinone |
| $QH_2$ | Ubiquinol ( = plastoquinol) |
| R | General symbol for remainder of a chemical formula, *e.g.*, an alcohol is R—OH ; also gas constant |
| $R_f$ | Resolution front |
| Rb | Ribosome |
| RBC, rbc | Red blood cell(s) or erythrocyte(s) |
| RDA | Recommended dietary allowance |
| RIA | Radioimmunoassay |
| rpm | revolutions per minute |
| rps | revolutions per second |
| RQ | Respiratory quotient |
| RT | Room temperature |
| S | Substrate |
| S | Svedberg unit(s) |
| $S_f$ | Svedberg unit of flotation |
| SD | Standard deviation |
| SDS | Sodium dodecyl sulfate |
| sec | second(s) |
| SGOT | Serum glutamic-oxaloacetictronsaminase ( = aspartate aminotransferase) |
| SGPT | Serum glutamic-pyruvic transaminase ( = alamine aminotransferase) |
| SH | Sulfhydryl |
| sq cm | square centimetre(s) |
| std. | Standard |
| STP | Standard temperature and pressure (273° absolute, 760 mm Hg) |
| Str | Streptomycin |
| T | Absolute temperature |
| *T* | tara, a prefix denoting trillion, *i.e.*, million million or $10^{12}$ |
| TBW | Total body water |
| TEAE-cellulose | o-(triethylaminoethyl) cellulose |
| Tet | Tetracycline |
| TLC | Thin layer chromatography |
| $T_m$ | Melting temperature ( = denaturation temperature) |
| TMV | Tobacco mosaic virus |

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|---|---|
| Tris | Tris (hydroxymethyl) aminomethane, a buffer (tromethamine |
| TSI | Thyroid-stimulating immunoglobin, formerly called as LATS |
| U | Unit(s) |
| UV | Ultraviolet light |
| V | Volume |
| V | Volt |
| $V_o$ | Initial velocity |
| $V_{max}$ | Maximal velocity |
| WBC, wbc | White blood cell(s) or leukocyte(s) |
| WHO | World Health Organization |
| wk | Week(s) |
| XMP | Xanthosine monophosphate |
| Yr | Year(s) |
| μ | micro, a prefix denoting one millionth, *i.e.*, one thousand thousandth or $10^{-6}$ |
| Δ | Change in (Example : ΔV = change in volume) ; In steroid nomenclature, Δ followed by a number (*e.g.*, $\Delta^{4-}$) indicate the position of a double bond |
| ΔG | Free-energy change |
| ΔG°′ | Standard free energy change |
| Δ*H* | Enthalpy change |
| Δ*S* | Entropy change |
| [ ] | Concentration of |
| $[\alpha]_D t$ | Specific rotation |
| λ | Wavelength |
| Z | Net charge |

# APPENDIX IX

## THE NOBEL PRIZES

The Nobel Prizes are among the world's most venerated awards. Originally, they were a gesture of peace by a man whose discovery had unintentionally added to the destructive forces of warfare.

**ALFRED BERNHARD NOBEL**
The originator of the Nobel Prizes, the world's most venerated annual awards

A restless, melancholy man, **Alfred Bernhard Nobel** was one of the most imaginative of 19th century inventors. He was an engineer, a chemist, a philanthropist, a litterateur, an eccentric genius, and a linguist who could speak 6 languages. He was born on October 10, 1833 as 4th son to Immanuel and Caroline Nobel. His father Immanuel was a Swedish munitions expert, an inventor and engineer who had married Caroline Andrietta Ahlsell in 1827. The couple had 8 children, of whom only Alfred and 3 brothers reached adulthood. Alfred was prone to illness as a child, but he enjoyed a close relationship with his mother and displayed a lively intellectual curiosity from an early age. Nobel, who remained unmarried and had no childen, was closely associated with Countess Bertha Kinsky, who was a prominent Austrian pacifist. As a young engineer, he developed an interest in nitroglycerine, the oily substance that was 25 times more explosive than gunpowder. In 1863, Nobel obtained a patent for a detonator of mercury fulminate, and within 4 years he succeeded in solidifying nitroglycerine by mixing it with a type of sandy clay. The mixture was called **dynamite** (*dynamis*[G] = power).

Dynamite had a clear advantage over other explosives because it could be transported easily and handled without fear. It became an overnight success and was adapted to applications in mining, tunnel construction, and bridge and road building. Before long, it was being used in armanents on the battlefield. Nobel patented dynamite in 1867. He then turned his attention to military explosives, where the main requirement was for a smokeless powder, and achieved success with his combination of nitroglycerine with gun cotton known as **ballistite** (1888).

Nobel soon amassed a fortune through control of several European companies that produced dynamite. However, toward the end of his life, he became a pacifist and began speaking out against the use of dynamite in warfare. In 26 lines of his handwritten will, Nobel directed that the bulk of his estate should be used to award prizes that would promote peace, friendship, and service to humanity. It is certain that the awards he instituted reflect his lifelong interest in the fields of Physics, Chemistry, Physiology or Medicine, and Literature. However, there is also abundant evidence that his friendship with his one-time secretary Countess Bertha inspired him to establish the prize for peace. When Nobel first proposed a prize for world peace in 1883, it is interesting that he suggested it be given for the first 30 years only. He was optimistic that the world would realize the ravages of war and prize the peace dividend. Coincidentally, Hitler's putsch in Munich began just then. *Nobel prizes are not awarded posthumously.* The physics and chemistry prizes are awarded by committees chosen from the Swedish Academy of Sciences and the physiology prize by the Carolinian Institute, its medical equivalent.

After his childhood, Nobel only lived in Sweden for a few years (in the 1860s) to set up nitroglycerine manufacture, and again toward the end of his life when he took over the Bofors ironworks for conversion to a munitions factory. Otherwise he lived in France, in Italy and travelled constantly, "the wealthiest vagabond in Europe''; he called himself. By 1895, Nobel had developed angina pectoris and he died of a cerebral hemorrhage at his village in San Remo, in Italy, on December 12, 1896.

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After his death, the Governments of Sweden and Norway established **Nobel Memorial Prizes** in 5 categories: Chemistry, Physics, Physiology or Medicine, Literature, and Peace. A 6th category, Economics, was established by the Central Bank of Sweden in 1968 and first awarded in 1969 (Curiously enough, there is no provision for a Nobel prize in Mathematics). Each year, Nobel Laureates assemble at Oslo or Stockholm on December 10, the anniversary of Nobel's death. Each laureate receives a medallion, a scroll, and all or part of a cash award, currently valued at 7.8 million kronor (*i.e.*, about one million dollars) per category. Until 1980, the Nobel medal was made of 23-carat gold and weighed about 175 grams. Since then, the medallion is being made of 18-carat green-gold-plated with 24-carat gold.

**The Nobel Medallion**
In the background (on the left) is the sketch of Rabindranath Tagore, the 1913 Nobel Laureate for Literature from India.

Although Alfred Nobel made his fortune inventing and marketing dynamite, but is much more remembered the world over for bequeathing his legacy for the 6 annual prizes instituted in the 20th century. Only speculations can be made about the reasons for Nobel's establishment of the prizes that bear his name. He was reticent about himself, and he confided in no one about his decision in the months preceding his death. The most plausible assumption is that a bizarre incident in 1888 may have clicked the idea that culminated in his bequest for the Nobel Prizes. In fact, that his brother Ludwig Nobel, who himself made his millions in oil, had died while staying in Cannes, France. The French newspapers reported Ludwig's death but confused him with Alfred; one paper sported the headline "*Le marchand de la mort est mort*" ("The merchant of death is dead".). While other papers made critical comments on his explosive contribution for wartime destruction of man by man. Perhaps, Nobel established the prizes to avoid precisely the sort of posthumous reputation aired by the newspapers. Thus, the millionaire Alfred also provides the rare instance of a celebrity who read his own obituaries. In the end, Nobel came to dislike those very forces of military competition that had made him rich. Money never brought Nobel happiness, nor release him from loneliness and distrust. Such was a 'nobel' Nobel !

Not surprisingly, then, a few countries have dominated in the Nobel stakes. Germany was first, and won the lion's share of science prizes until the 1930s, but the onset of Nazism and the flight of refugees to the U.S. brought about a clear American lead that has continued ever since. But even after World War II, many North American laureates have been immigrants. Up to 1986, United States citizens had won 47 physics prizes, 57 medicine and 29 chemistry prizes. Only in chemistry did Germany come anywhere near, with 24, while in physics and medicine/physiology Britian came a poor second with 20 in each, and Germany third with 15 and 11, respectively.

The first Nobel Prize were announced in 1901. Among the recipients were :

1. **Wilhelm Konrad Rontgen** (LT, 1845-1923), a German physicist, for his discovery of x-rays which heralded the age of modern physics and revolutionized diagnostic medicine.
2. **Jacobus Henricus van't Hoff** (LT, 1852–1911), a Dutch physical chemist, for formulating the laws of chemical dynamics and of osmotic pressure.
3. **Emil (Adolf) von Behring** (LT, 1854-1917), a German biologist and the founder of the science of immunology, for his work on serum therapy, especially in developing a vaccine against tetanus and diptheria.
4. **Jean Henri Dunant** (LT, 1828-1910), a Swiss humanitarian, for peace. He was founder of the Red Cross, in 1864 (now Red Cross and Red Crescent).

Till 2003, six Indians have been honoured with the coveted Nobel Prize. They are :

1. **Rabindranath Tagore** (LT, 1861-1941), in 1913 for *Literature* for his classical work Gitanjali (1910). He was a Bengali poet, short-story writer, song composer, playwright, essayist, and painter (He published several books of poetry in the 1880s and completed Manasi (1890), a collection that marks the maturing of his genius), He was awarded a knighthood in 1915, but he repudiated it in 1919 as a protest against the Amritsar Massacre.
2. **Chandrashekhar Venkat Raman** (LT, 1888-1990), in 1930 in *Physics,* for his laws on light scattering, better known as 'Raman effect'.
3. **Har Gobind Khorana** (born, 1922), in 1960 in *Physiology or Medicine*, for deciphering genetic code . In 1970, he and his research team synthesized the first artificial copy of a yeast gene.
4. **Subrahmanyan Chandrasekhar** (LT, 1910-1995), in 1983 in *Physics* (along with William Alfred Fowler) for his theory on black holes. He is best known for what was later called as 'Chandrasekhar limit'. It is interesting to note that two of Subrahmanyan's former students T.D. Lee and C.N. Yang got 1957 Nobel Prize for discovering violations of the principle of parity. And the teacher, in a strange quirk of fate, had to wait for 26 years to join his students in the pantheon of Nobel Laureates.
5. **Mother Teresa** (LT, 1910-1997), in 1979 for *Peace,* in recognition of her missionary activities.
6. **Amartya Sen** (born, 1933), in 1998 in *Economic Science,* for his contributions to welfare economics and social choice and for his interest in the problems of society's poorest members. Sen was best known for his work on the causes of famine, which led to the development of practical solutions for preventing/limiting the effects of real/perceived shortages of food.

# APPENDIX X

## A CHRONOLOGY OF BIOCHEMISTRY

Certain key discoveries greatly influence the development of a particular discipline of study. This appendix presents some of the major landmarks in the progress of biology, biochemistry in particular and the individuals whose names are commonly associated with them. It is very difficult to appraise the historical development of any field of study. One investigator often gets the credit for an important discovery when many others should share in the honour. Many 'unlucky' others go in history unnoticed, while some of them get recognition posthumously. No one individual has a monopoly on ideas; advances in science are built on the work of many minds. Especially in recent years, important discoveries have resulted from the efforts of teams of investigators. Furthermore, because knowledge of a topic accrues over a period of time, it is often difficult to decide in which year the "discovery" *actually* occurred. In this brief outline, the student may be able to see some of the relationships that exist between one discovery and another. The discoveries are not completely isolated, as they may sometimes appear. One may also notice that fundamental discoveries in a particular branch of biology tend to be grouped fairly close together chronologically because that particular interest may have dominated the thought of the biological investigators at that time.

Biochemistry had its earliest origin in speculations of the role of air in the utilization of food and on the nature of fermentation. **Leonardo da Vinci** (1452-1519) was one of the first to compare animal nutrition to the burning of a candle. This sort of line of reasoning was further developed by **van Helmont** in 1648. However, the real history of biochemistry began during the late 18th century when the science of chemistry began to take form.

### 18th Century

1770-1774 **Joseph Priestley** –discovered oxygen and showed that it was consumed by animals and produced by plants.

1770-1786 **Karl Wilhelm Scheele** –isolated glycerol from olive oil, as well as citric, malic, lactic and urin acids from natural sources.

1773 **Rouelle**–isolated urea from urine.

1779-1796 **Ingen-Housz**–showed that light is required for oxygen production by green plants; also proved that plants use carbon dioxide.

1780-1789 **Antoine Laurent Lavoisier** –demonstrated that animals require ozygen; recognized that respiration is oxidation; and first measured oxygen consumption by a human subject.

1783 **Lazaro Spallanzani**– deduced that protein digestion in the stomach is a chemical rather than mechnical process.

### 19th Century

1804 **John Daltoner**–enunciated the atomic theory.

1804 **De Saussure** –carried out the first balance sheet for the stoichiometry of gas exchanges in photosynthesis.

1806 **Vauguelin** and **Robiquet**–first isolated an amino acid, asparagine (Asn).

1815 **Biot** –discovered optical activity.

1828 **Friedrich Wöhler**–synthesized the first organic compound from inorganic components: urea from lead cyanate and ammonia.

1830–1840 **Justus von Liebig**–developed techniques of quantitative analysis and applied them to biological systems.

1833 **Payen** and **Persoz**–purified diastase (amylase) of wheat, showed it to be heat-labile,

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and postulated the central importance of enzymes in boilogy.

1837 **Jöns Jacob Berzelius**–postulated the catalytic nature of fermentation.

1838 **Mattias J. Scheleiden** and **Theodore Schwann**–erunciated the cell theory.

1838 **Geradus Johannes Mulder**–carried out the first systematic studies of proteins; also proposed the name "proteine", later "protein," for the basic constituents of protoplasmic materials.

1842 **Herman von Helmholtz** and **J. R. von Mayer**–enunciated the First Law of thermodynamics and its applicability to living organisms.

1847 **Durburn faut**–degraded starch to maltose by diastase.

1850–1855 **Claude Bernard**–isolated glycogen from the liver and showed that it is converted into blood glucose.

1854–1864 **Louis Pasteur**–proved that fermentation is caused by microorganisms and demolished the spontaneous generation hypothesis. famous for his aphorism : *omne vivum e vivo* (every living thing from the living).

1857 **Kölliker**–discovered mitochondria ("sarcosomes") in muscle.

1859 **Charles Darwin**–published 'Origin of Species' and developed the concept of natural selection as a factor in evolution.

1862 **Sachs**–proved that starch is a product of photosynthesis.

1864 **F. Hoppe-Seyler**–first crystallized a protein, hemoglobin which he also renamed.

1866 **Gregor Johann Mendel**–published his experiments leading to the principles of independent segregation and assortment of genes, thus formulated the first two laws of heredity.

1869 **Friedrich Miescher**–isolated DNA for the first time.

1877 **Friedrich Wilhelm Kuhne**–coined the term 'enzyme' and distinguished enzymes from bacteria.

1879 **Albrecht Kossel** – isolated nucleproteins in the heads of fish sperm (Nobel Laureate, 1910)

1886 **MacMunn**–discovered histohematins, later renamed cytochoromes.

1887 **Emil Fischer** – described structural patterns of proteins (Nobel Laureate, 1902).

1890 **Altmann**–described procedures for staining mitochondria, studied their distribution, and postulated them as having metabolic and genetic autonomy.

1893 **Ostwald**–proved enzymes are catalysts.

1894 **Emil Fischer**–demonstrated the specificity of enzymes and the lock-and-key relationship between enzyme and substrate.

1895 **W. Roentgen**–observed that a new form of penetrating radiation, which he named x-rays, was produced when cathode rays (electrons) hit a metal target (Nobel Laureate, 1901).

1897 **Bertrand**–christened the term 'coenzyme'.

1897 **Eduard Buchner** and **Hans Buchner**–showed that cell-free extracts of yeast can ferment sugars to form $CO_2$ and $C_2H_5$.OH, laying the foundations of enzmology.

1897 **Christian Eijkman**–proved that beriberi is a dietary deficiency disease, and that a water-soluble component of rice polishings can cure it (Nobel Laureate, 1929).

## 20th Century

1901–1904 **J. Takmine** and **Aldrich**, and also **J.J.Abel**–first isolated a hormone, epinephrine. **Stoltz**–achieved its synthesis.

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| 1902 | **Emil fischer** and **Hofmeister**–demonstrated that proteins are polypeptides. |
| 1903 | **Carl Neuberg**–first used the term 'boichemistry'. |
| 1904 | **William M. Bayllis** and **Ernest H. Starling**–demonstrated the action of secretin, a hormone from the mucosa of the stomach; this marked the real birth of the science of endocrinology. |
| 1905 | **Knoop**–deduced the β-oxidation of falty acids. |
| 1905 | **Harden** and **Young**–showed the reqquirement of phosphate in alcoholic fermentation and isolated the first coenzyme, coxymase, later shown to be NAD. |
| 1906 | **Michael Tswett**–invented column chromatography, passing petroleum extracts of plant leaves through columns of powered chalk. |
| 1906 | **Frederick Gowland Hopkins** – explained dietary bya biochemical investigation of the lack of essential amino acids in the diet (Nobel Laureate, 1929). |
| 1907 | **Fletcher Gowland Hopkins**–showed that lactic acid is formed during anaerobic muscle contraction. |
| 1909 | **Soren Sörensen**–showed the effect of pH on enzyme action. |
| 1911 | **Casimer Funk**–isolated crystals with vitamin B activity and coined the term 'vitamine'. |
| 1912 | **Batelli and Stern**–discovered dehydrogenases. |
| 1912 | **Carl Neuberg**–proposed a chemical pathway for fermentation. |
| 1912 | **Warburg**–postulated a respiratory enzyme for the activation of oxygen; also showed the requirement of iron in respiration. |
| 1912–1922 | **Wieland**–showed the activation of hydrogen in dehydrogenation reactions. |
| 1913 | **Leonor Michaelis** and **Maud Menten**–proposed a kinetic theory of enzyme action. |
| 1913 | **Willstätter** and **Stahl**–isolated and studied chlorophyll. |
| 1914 | **Edward C. Kendall**–isolated the hormone, thyroxine, which was later (1927) artificially synthesized by Harington. |
| 1917 | **Elmer Mc Collum**–showed that zerophatalmia in rats is due to lack of vitamin A. |
| 1919 | **Francis W. Aston –** discovered isotopes (Nobel Laureate, 1922). |
| 1921 | **Frederick Gowland Hopkins –** isolated glutathione |
| 1921 | **Loewi, Otto** and **H.H. Dale** – isolated acetylcholine (Nobel laureates, 1936). |
| 1922 | **Ruzicka**–recognized isoprene as the building block of many natural products, *i.e.*, propounded isoprene rule. |
| 1922 | **Elmer McCollum**–showed that lack of vitamin D causes rickets. |
| 1922 | **Otto Warburg**–devised monometric methods for studying metabolism of living cells (Nobel Laureate, 1931). |
| 1925 | **Briggs** and **John B.S. Haldane**–made important refinements in the theory of enzyme kinetics. |
| 1925 | **Walter Norman Howorth**–formulated sugars as pyranoses. |
| 1925 | **David Keilin**–coined the term 'cytochrome'. |
| 1925–1926 | **George R. Minot, George William Murphy** and **G.H. Whipple**–discovered liver treatment of pernicious anemia (Nobel Laureates, 1934) |
| 1925–1930 | **Levene**–elucidated the structure of mononucleotides and showed that they are building blocks of nucleic acids. |
| 1925–1930 | **Theodore Svedberg**–developed the first analytical ultracentrifuge and used it to estimate the MW of hemoglobin as 68,000. |

1926 **James B. Sumner**–first obtained crystals of an enzyme, uresase from extracts of jack beans (*Canavalia ensiformis*) proved it to be a protein (Nobel Laureate, 1946).

1926 **Hisaw**–discovered a hormone, relaxint.

1926 **Jansen** and **Donath**–isolated vitamin $B_1$, thiamine from rice polishings.

1927 **Adolf Windaus**–showed ergosterol as a precursor of vitamin D.

1927 **P. Eggleton, G.P. Eggleton, C.H. Fiske** and **Y. Subbarow** – demonstrated the role of phosphagen (phosphocreatine) in muscular contraction.

1928 **Euler**–isolated carotene and showed it to have vitamin A activity.

1928 **Albert Szent-Györgyi**–isolated vitamin C (ascorbic acid) from paprika plant (Nobel laureate, 1937).

1928 **H. Wieland** and **Adolf Windaus** – established the structure of cholesterol molecule (Noble Laureates, 1927, 1928)

1928–1933 **Warburg**–deduced the iron–porphyrin nature of the respiratory enzyme.

1929 **K. Lohamann, C. Fiske** and **Y. Subbarow**–isolated a labile phosphate (*i.e.*, ATP) and phosphocreatine from muscle extracts.

1929 **A. Butenandt** and **E.A. Doisy** – the first-ever isolation of a sex hormone (estrone) by these two investigators, independently (Doisy, Nobel laureate, 1943).

1930–1933 **John H. Northrop**–isolated crystalline pepsin and trypsin and proved their protein nature.

1930–1935 **Edsall** and **von Muralt**–isolated myosin from muscle.

1931 **Linus Carl Pauling**–published his first essays on "The Nature of the Chemical Bond", detailing the rules of covalent bonding.

1931 **Englehardt**–discovered that phosphorylation is coupled to respiration.

1932 **C. Glen King** and **W.A. Waugh**–isolated ascorbic acid from lemon juice.

1932 **Warburg** and **Christian**–discovered the 'yellow enzyme' (vitamin $B_2$ or riboflavin), which is a flavoprotein.

1932 **A. Bethe** – developed the concept of ectihormone (pheromone)

1933 **Hans Adolf Krebs** and **Kurt Hanseleit**–discovered the urea cycle.

1933 **Keilin**–isolated cytochrome *c* and reconstituted electron transport in particulate heart preparations.

1933 **Gustave Embden** and also **Otto Meyerhof**–demonstrated crucial intermediates in the chemical pathway of glycolysis and fermentation.

1933 **Arne W.K. Tiselius**–introduced electrophoresis for separating proteins in solution.

1933 **M. Goldblatt and U.S. von Euler –** discovered prostaglandins.

1933 **George Wald** – discovered the presence of vitamin A in the retins of the eye (Nobel lautrate, 1967).

1934 **V. B. Wogglesworth–**discovered the role of corpus allatum gland in insect metamorphosis.

1934 **Carl P. Henrik Dam** and **Edward A. Doisy** – isolated and synthesized vitamin K (Nobel Laureates, 1943).

1935 **Rose**–discovered theromine, the last essential amino acid to have been recognized.

1935 **Robert R. Williams et al**–deduced the structure of vitamin $B_1$ (thiamine).

1935 **Wendell M. Stanley**–first crystallized a virus, tobacco mosaic virus (Nobel laureate, 1946).

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| 1935 | **Schoneheimer** and **Rittenberg**–first used isotopes as tracers in the study of intermediary metabolism of carbohydrates and lipids. |
| 1935 | **B. Hansteöm** – discovered the presence of the X-organs in crusaceans. |
| 1935–1946 | **Edward C. Kendall** and **P.S. Hench –** dicovered a hormone, cortisone (Nobel Laureates, 1950). |
| 1935–1936 | **Warburg** and **Van Euler**–isolated and determined the structure and action of pyridine lucleotides. |
| 1937 | **Hans Adolf Krebs**–postulated the citric acid cycle or Krebs cycle (Nobel laureate, 1953). |
| 1937 | **Lohman** and **Schuster**–showed that thiamine is a component of the prosthetic group of pyruvate carbomylase. |
| 1937 | **Carl F. Cori** and **Gerti T. Cori**–began their incisive studies of glycogen phosphorylase. |
| 1937 | **G. W. M. Findley** and **F.O. MacCollum** – discovered interferon. |
| 1937 | **P.Köenig** and **Arne W. K. Tiselius** – developed electrophoresis. |
| 1938 | **Theodor Svedberg** – developed ultracentrifuge (Nobel laureate, 1926). |
| 1938 | **Hill**–found that cell-free subpensions of chloroplasts yield $O_2$ when illuminated in the presence of an electron acceptor. |
| 1938 | **Braunstein** and **Kritzmann**–discovered transmination reactions. |
| 1938 | **Beherens**–employed differential centrifugation to separate nuclei and cytoplasm from liver cells, a technique further developed for the fractionation of cell organelles by claude, brachet, Hogeboom and others in the 1940s and early 1950s. |
| 1939–1941 | **Fritz A. Lipmann**–postulated the central role of ATP in the energy transfer cycle. |
| 1939–1942 | **Engelhardt** and **Ljubimova**–discovered ATPase activity of myosin. |
| 1939–1946 | **Albert Szent-Györgyi**–discovered actin and myosin and elucidated the role of ATP in muscular contraction. |
| 1940 | **George Beadle** and **Edward Tatum**–proposed the one gene-one enzyme hypothesis. |
| 1940–1943 | **Claude**–isolated and studied a mitochondrial fraction from liver. |
| 1941 | **W.T. Astbury**–obtained the first x-ray diffraction pattern of DNA. |
| 1941 | **Carl F. Cori** and **Gerti T. Cori** – elucidated lactic acid metabolic cycle (Nobel Laureates, 1947). |
| 1942 | **D. McClean** and **L.M. Rowlands** – discovered the enzyme hyaluronidase in mammalian sperm. |
| 1942 | **Konrad S. Bloch** and **Rittenberg**–discovered that acetate is the precursor of cholesterol. |
| 1942 | **A.J.P. Martin** and **R.L.M. Synge**–devolped partition chromatography, leading to paper chromatography two years later. |
| 1943 | **Chance**–first applied sensitive spectrophotometric methods to enzyme–substrate interactions. |
| 1943 | **A. Claude –** isolated various cell constituents (such as mitochondria, microsomes and nuclei) by differential; centrifugation (Nobel Laureate, 1974). |
| 1943–1947 | **Leloir** and **Munoz**–demonstrated fatty acid oxidation in cell-free systems. |
| | **Albert L. Lehminger**–showed the requirement of ATP and the stoichiometry of falty acid oxidation. |
| 1944 | **Ostwald T. Avery, Colin M. Macleod** and **Maclyn McCarty**–demonstrated that bacterial transformation is caused by DNA, *i.e.*, DNA is genetic material. |
| 1944 | **Selman Waksman**–discovered streptomycin. |

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| 1945 | **Keith R. Porter –**analyzed the fine structure of endoplasimic reticulum. |
| 1947 | **P. Holtz**– discovered norepinephrine (=noradrenalin). |
| 1947–1950 | **Fritz A. Lipmann** and **Kaplan**–isolated and characterized coenzyme A. |
| 1948 | **Leloir**–discovered the role of uridine nucleotides in carbohydrate biosynthesis. |
| 1948 | **Hogeboom, Schneider** and **Palade**–refined the differential centrifugation method for cell fractionation. |
| 1948 | **Alexander Ogston**–proposed a 3-point attachment hypothesis for citrate behaviour. |
| 1948 | **Melvin Calvin** and **Benson**–discovered that phosphoglyceric acid is an early intermediate in photosynthetic $CO_2$ fixation. |
| 1948–1950 | **Eugene P. Kennedy** and **Albert L. Lehninger**–discovered that the citric acid cycle, falty acid oxidation and oxidative phosphorylation take place in mitochondria. |
| 1948–1950 | **Loomis** and **Fritz A. Lipmann**–deduced the action of uncoupling agents. |
| 1949 | **Albert Szent-Györgyi**–showed that isolated myofibrils from skeletal muscle cells contract upon addition of ATP. |
| 1949 | **U.S. von Euler** – isolated and identified norepinephrine as the neurotransmitter in the synpathetic nervous system (Nobel laureate, 1970). |
| 1950–1953 | **Erwin Chargaff**–discovered the base equivalences in DNA. |
| 1951 | **Fritz A Limmann** and **Lynen**–elucidated 'active' acetate *i.e.*, acetyl coenzyme A. |
| 1951 | **Brakke**–used density-gradient centrifugation in sucrose solutions to purify a plant virus. |
| 1951 | **Albert L. Lehminger**–demonstrated that oxidative phosphorylation is coupled to electron transport in respiratory chain. |
| 1951 | **Linus Carl Pauling** and **Robert Corey**–proposed the structure of helical conformation of a chain of L-amino acids- the α-helix, and the structure of the β-sheet, both of which were later found in many proteins (Pauling, Twice Nobel Laureate, 1954 and 1962). |
| 1952 | **George E. Palade**–analyzed the fine structure of the mitochondrion (Nobel Laureate, 1974). |
| 1952–1953 | **Palade, Porter** and **Sjöstrand**–perfected thin sectioning and fixation methods for electron microscopy of intracellular structures. |
| 1952–1954 | **Paul Zamecnik et al**–discovered that ribonucleoprotein particles, later named ribosomes are the site of protein synthesis, also developed the first cell-free system to carry out protein synthesis. |
| 1953 | **James D. Watson** and **Francis Harry Compton Crick**–proposed the donble-helix model of DNA, based on x-ray diffraction patterns obtain by Rosalind Franklin and Maurice Wilkins. (Waton, Crick and Wilkins, Nobel Laureates, 1962) |
| 1953 | **V. du Vigneaud**–carried out the first laboratory synthesis of the peptide hormones ocytocin and vasopressin. |
| 1953 | **Horecker, Dickens** and **Racker**–elucidated the 6-Phosphogluconate pateway of glucose catabolism. |
| 1954 | **Christian de Duve**–isolated lysosomes, and later peroxisomes by centrifugation (Nobel laureate, 1974). |
| 1954 | **Arnon et al**–discovered photosynthetic phosphorylation. |
| 1954 | **Max F. Perutz et al**–developed heavy-atom methods to solve the phase problem in protein crystallography. |
| 1954 | **Hute Huxley**—proposed the sliding filament model for muscular contraction. |
| 1955 | **Frederick Sanger**–completed the analysis of amino acid sequence of bovine insulin, the first protein to the sequenced (Twice Nobel Laureate, 1958 and 1980). |

1955 **Kennedy and Weiss**–described the role of CTP in the biosynthesis of phosphatidylcholine.

1955–1957 **Arthur Kornberg** and **Severo Ochoa** – synthesized DNA (Kornberg) and RNA (Ochoa) artificially outside of cells, *i.e.*, in vitro (Nobel Laureates, 1959)

1956 **Umbarger**–reported that the end product isoleucine inhibits the first enzyme in its biosynthesis from threonine.

1956 **Dorothy Crowfoot Hodgkin**–determined the structure of coenzyme $B_{12}$.

1956 **Ingram**–showed that normal and sickle-cell hemoglobin differ in a single amino acid residue.

1956 **Christian B. Anfinsen** and **White**–concluded that the three-dimensional conformation of proteins is specified by their amino acid sequence.

1956 **Luis F. Leloir**–determined the pathway to uridine diphosphate glucose (UDPG).

1957 **Earl Wilbur Sutherland** and **T.W. Rall**–discovered cyclic adenosine-3′5′ monophosphate (=cyclic AMP), an intracellular mediating agent, found in all living animal tissues (Sutherland, Nobel Laureate, 1971).

1957 **Hans Adolf Krebs** and **H.L. Kornberg**–discovered the glyoxylate cycle.

1957 **Mathew S. Meselson, Frank W. Stahl** and **Vinograd–**developed equilibrium density-gradient centrifugation in $CsCl_2$ solutions for separating nucleic acids.

1957 **Arthur Kornberg**–discovered DNA polymerase, the enzyme now used to produce labelled DNA probes.

1957 **Melvin Calvin** – elucidated chemical pathways in photosynthesis by using radioactive carbon 14 (Nobel Laureate, 1961)

1957 **Hoagland, Zamecnik** and **Stephenson**–isolated tRNA and determined its function.

1958 **A.B. Learner** – discovered the hormone melatonin in the pieneal gland.

1958 **A.F.J. Butenandt et al** – chemically analyzed the first pheromone-the sex attractant substance of silk moths (*Bombyx mori*) and named it as bombykol

1958 **Weiss, Hurwitz** and **Stevens** – discovered DNA-directed RNA polymerase.

1958 **Meselson** and **Stahl** – demonstrated that DNA is replicated by a semiconservative mechanism.

1959 **Wakil** and **Ganguly** – reported that malonyl-CoA is a key intermediate in fatty acid biosynthesis.

1959–1960 **Rosalyn Yalcw** and **S.A. Berson** – developed the technique of radiommunoassay (Yalow, Nobel Laureate, 1977).

1960s–1970s **S. Bergstöm, B. Samuelsson** and **J. Vane –** characterized the prostalandins, the chemical transmitters of intracellular and intercellular signals, Bergström is credited with isolating prostaglandins and determining their structures; Samuelsson with determining their biosynthesis and metabolism; and Vane for discovering prostacyclin (Nobel Laureates, 1982).

1960 **John C. Kendrew**–described the first detailed 3-'D' structure of a protein (sperm whale myoglobin) to a resolution of 0.2 nm.

**Max F. Perutz**–proposed a lower-resolution structure of larger protein hemoglobin.

1960 **Efraim Racker et al**–extracted $F_1$ component of ATP synthetase.

1960 **William Moore** and **Stanford Stein**–determined the amino acid sequence of ribonuclease.

1961 **J.F.A. Miller** – established the function of the thymus gland, which was long known as a transitory organ.

1961 **Marshall W. Neirenberg** and **J.H. Matthaei**–deciphered the genetic code (Nirenberg, Nobel Laureate, 1968).

1961 **Marshall W. Neirenberg** and **Severo Ochoa**–decoded the base code of nucleic acids.

1961 **Francois Jacob** and **Jacques Monod**–presented a model for the regulation of gene activity called operon model (Nobel Laureates, 1965).

1961 **Peter Mitchell**–proposed chemiosmotic coupling hypothesis of ATP formation.

1961 **Harold Copp et al –** discovered a hormone, calcitonin.

1961 **Cross et al**–isolated gibberllins and elucidated their chemical structure.

1961 **Francois Jacob, Jacques Monod** and **Changeux**–proposed a theory of the function and mechanism of allosteric enzymes.

1961 **Marmur** and **Doty**–discovered DNA renaturation.

1962 **Efraim Racker et al**–isolated $F_1$ component of ATP synthetase from mitochondria and reconstituted oxidative phosphorylation in submitochondrial vesicles.

1963 **D.S. Letham**–coined the term 'cytokinins; also isolated zeatin.

1963 **C.F. Eagles** and **P.R. Wareing**–isolated a plant growth inhibitor, dormin.

1963 **John Cairns**–demonstrated the existence of circular DNA in a bacterium.

1965 **Robert W. Holley et al**–determined for the first time the base sequence of a nucleic acid (Nobel Laureate, 1968).

1966 **Marshall H. Nirenberg, Severo Ochoa** and **Arthur Kornberg**–elucidated the genetic code.

1966 **David C. Phillips et al**–described the 3-'D' structure of lysozyme, the first enzyme to be analyzed in detail.

1966 **Marshall W. Nirenberg** and **Har Gobind Khorana**–presented a complete dictionary of nuclestide triplets (Nobel Laureates, 1968).

1966 **Maizel**–introduced the use of sodium dodecylsulfate (SDS) for high-resolution electrophoresis of protein mixtures.

1966 **Francis Harry Compton Crick**–proposed the wobble hypothesis.

1966 **Gilbert** and **Muller-Hill**–isolated the lac repressor.

1967 **Waclow Szybalski –**determined that only one strand of DNA is transcribed.

1967 **Gellert**–discovered DNA ligase, the enzyme used to join DNA fragments together.

1968 **Glomset**–proposed the theory of reverse cholesterol transport in which HDL is involved in the return of cholesterol to the liver.

1968 **Meselson** and **Yuan**–discovered the first DNA restriction enzyme. Shortly after, **Smith** and **Wilcox** discovered the first restriction enzyme that cuts DNA at a specific sequence.

1969 **Max Delbruck, Alfred D. Hershey** and **Salvadore E. Luria**–worked for the genetics of viruses suggesting the reproductive patterns.

1969 **Zubay** and **Lederman**–developed the first cell-free system for studying the regulation of gene expression.

1970 **David Baltimore, Howard M. Temin** and **Renatto Dulbecco**–studied the interaction between tomour viruses and the genetic material of the cell; discovered the reverse transcription (Baltimore and Temin, Nobel Laureates, 1975).

1970 **Gerald M. Edelman** and **R.R. Porter –** worked out the structure of gamma globulin (Nobel Laureates, 1972)

1971 **W.Y. Cheung** – discovered calmodulin.

1971 **Vane** – discovered that aspirin blocks the biosynthesis of prostaglandins.

1971–1973 **A.M. Cormack** and **G.N. Hounsfield** – invented the computer-assisted tomography (CAT) scanner (Nobel Laureates, 1979).

1972 **P.B. Woodard** and **A. Eschenmoser** – synthesized vitamin $B_{12}$.

1972 **M. Brown** and **J. Goldstein** – discovered the LDL receptor on cell surfaces; also explained the intracellur regulation of cholesterol metabilism (Nobel Laureates, 1985).

1973 **Cohen, Chang, Boyer** and **Helling** – reported the first DNA cloning experiments.

1975 **Dobberstein** and **Günter Blobel**–demonstrated protein translocation across membranes in a cell-free system (Blobel, Nobel Laureate, 1999).

1976 **W. Gilbert, A. Maxam,** and **Frederick Sanger** – devisd methods for determining base sequence in DNA (Gilbert and Sanger, Nobel Laureates, 1980).

1976 **J. Michael Bishop** and **Harold E. Varmus** – discovered oncogenes (Nobel Laureates, 1989)

1976 **Kim, Rich and Klug**–described the detailed 3-'D' structure of tRNA determined by x-ray diffraction.

1977 **Roger C.L. Guillemin** and **Andrew V. Schally**–synthesized peptide hormones.

1977 **McGarry, Mannaerts** and **Foster**–discovered that malonyl-CoA is a potent inhibitor of β oxidation.

1977 **Nishizuka et, al**–reported the existence of protein kinase C.

1977–1978 **Holmes and Klug**–determined the structure of TMV.

**Harrison and Rossman**–determined the structure of 2 small spherical viruses.

1978 **Susumu Tonegawa**–demonstrated DNA splicing for an immunoglobulin gene.

1981 **Steitz**–determined the structure of CAP protein.

1982 **Stanley B. Prusiner –** discovered a new biological principle of infection, under the name 'prion theory' (Nobel Laureate, 1997).

1982–1984 **Sidney Altman** and **Thomas R. Cech –** dicovered RNA catalysis (Nobel laureates, 1989).

1983 **Luc Montagnier**–discovered HIV, the cause of acquired immodeficiency syndrome (AIDS).

1984 **Rothman et al**–reconstituted Golgi vesicle trafficking *in vitro* using a cell-free system.

1984 **Schwartz** and **Cantor**–developed pulsed field gel electrophoresis for the separation of very large DNA molecules.

1984 **Hartmut Michel, Johann Deisenhofer** and **Robert Huber**–determined the structure of the bacterial photosynthetic reaction centre.

1985 **Kary B Mullis** – invented the polymerase chain reaction (PCR), a means of amplifying tiny amounts of DNA.

1988 **Elion** and **Hitchings** – designed and synthesized therapeutic purines and pyrimidines.

1989 **Snyder et al** – purified and reconstituted the inositol-1,3,4-$P_3$ receptor.

1991 **Roger Beachy** – demonstrated that plants can acquire resistance to viral pathogens.