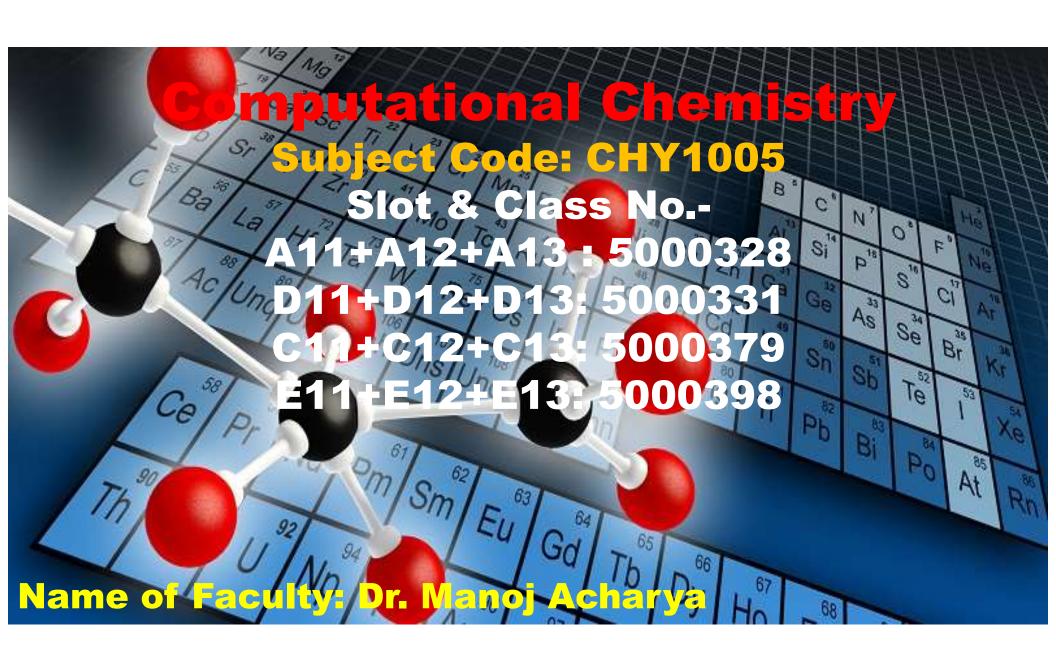Welcome
To
The Department of Chemistry

Dr. Manoj Acharya has completed his Doctorate from the Department of Chemistry at Motilal Vigyan Adarsh Mahavidyalaya, Bhopal. He has done his M.Sc. with specialization in Physical Chemistry and B.Sc. with specialization in Mathematics from Barkatullah University, Bhopal.

He is having 11 years of industrial and 13 years of academic experience. He has worked for esteemed organizations like Asian Paints (I) Limited and Lupin Limited. **He has hands-on experience & specialization in Green Corrosion Inhibitors, Polymer Chemistry, Spectroscopy, Electrochemistry, Environmental Science, Cephalosporins, Water Systems and Product Standardization etc.**

Worked as an auditor for ISO: 9001-2000 certification and is conversant with Environmental ISO-14001 system. Having rich experience in the implementation of Kizen (5S), TPM and has conducted HAZOP study and Statistical Process Control in APIL and Lupin Limited. He is trained in developing Entrepreneur Incubation Cell by Entrepreneur Development of India. He has wide exposure in SAP R/3 (PP Module), Enterprise Resource Planning (ERP), I2 and Offshore Project Management. He is Editorial Board Member of International Journal of Bioscience and Technology, reviewer of Journal of Applied Electrochemistry and has publications in renowned international journals. **His area of interest includes research in Green Corrosion Inhibitors, Batteries and Natural Products.**

Computational Chemistry

Subject Code: CHY1005

Slot & Class No.-
A11+A12+A13 : 5000328
D11+D12+D13: 5000331
C11+C12+C13: 5000379
E11+E12+E13: 5000398

Name of Faculty: Dr. Manoj Acharya

- ✓ Syllabus

- ✓ Schedule of Instruction

- ✓ Evaluation Pattern

- ✓ Time Table

- ✓ Module -1

Syllabus

Module	Description
Module Description	
I	**Introduction** Overview of the course, history and promises of computational chemistry, tools for computational chemistry, units, errors in computed quantities
II	**Quantum Chemistry** Historical development, Bohr's atomic model, de Broglie wavelength, Heisenberg uncertainty principle, Schrodinger equation, Wave function, particle in a box, Hydrogen atom, radial and angular solution to hydrogen atom, applications and limitations
III	**Thermodynamics** Intensive and extensive variables, state and path functions, Laws of Thermodynamics (First law and enthalpy; second law and entropy, spontaneity, and equilibrium; third law and absolute entropy) free energy, Gibbs and Maxwell's relations, Ideal and real gases

Module Description	
Module	**Description**
IV	**Potential Energy Surfaces** Chemical bonds and intermolecular interactions, Types of intermolecular interactions (charge distribution of isolated molecules, electrostatic interaction, induction interaction, London or dispersion forces, hydrogen bonding, repulsive interaction, relative contribution of different terms), representing the potential energy surfaces (pair additivity, rare gas), intramolecular interactions (bond stretching, angle bending, torsional and improper terms).
V	**Molecular Dynamics** Introduction to ensembles, force fields, integration of Newton's laws of motion, force calculation, energy minimization, periodic boundary conditions, choice of input configuration, velocities, and time-step, applications, and calculation of simple thermodynamic variables.

Schedule of Instructions

Schedule of Instruction: Till CAT- I				
Time Period	**Topics/Module**	**No. of Sessions**	**Activity**	**Weightage**
Till Mid Term	**Introduction** Overview of the course, history and promises of computational chemistry, tools for computational chemistry, units, errors in computed quantities	3		MST : 20 % TEE – 20 %
	Quantum Chemistry Historical development, Bohr's atomic model, de Broglie wavelength, Heisenberg uncertainty principle, Schrodinger equation, Wave function, particle in a box, Hydrogen atom, radial and angular solution to hydrogen atom, applications and limitations	9		MST: 20 % TEE – 20 %

Cont..

Schedule of Instruction: Till CAT- I				
Time Period	**Topics/Module**	**No. of Sessions**	**Activity**	**Weightage**
Till MST & MST To TEE	**Thermodynamics** Intensive and extensive variables, state and path functions, Laws of Thermodynamics (First law and enthalpy; second law and entropy, spontaneity, and equilibrium; third law and absolute entropy) free energy, Gibbs and Maxwell's relations, Ideal and real gases	9		MST : 20 % TEE – 20 %
	Potential Energy Surfaces Chemical bonds and intermolecular interactions, Types of intermolecular interactions (charge distribution of isolated molecules, electrostatic interaction, induction interaction, London or dispersion forces, hydrogen bonding, repulsive interaction, relative contribution of different terms), representing the potential energy surfaces (pair additivity, rare gas), intramolecular interactions (bond stretching, angle bending, torsional and improper terms)	9		MST: 20 % TEE – 20 %

Cont..

Schedule of Instruction: Till CAT- I				
Time Period	**Topics/Module**	**No. of Sessions**	**Activity**	**Weightage**
MST To TEE	**Molecular Dynamics** Introduction to ensembles, force fields, integration of Newton's laws of motion, force calculation, energy minimization, periodic boundary conditions, choice of input configuration, velocities, and time-step, applications, and calculation of simple thermodynamic variables.	9		MST : 20 % TEE – 20 %

Books

✓ *Atkins' Physical Chemistry*, Peter Atkins and Julio De Paula, Oxford University Press, 201
✓ "Molecular Modelling: Principles and Applications" A. Leach
✓ "Understanding Molecular Simulation: From Algorithms to Applications" Berend Smit and Daan Frenkel

Evaluation Pattern

S.No.	Activity	Weightage (%)
	Evaluation Pattern	
1	MST	30
2	TEE	30
3	Attendance	5
4	Class Assessment (a) Group Activity (5) (b) Quiz (10) (c) Tutorials (10) (d) Assignment (10)	35

Time Table & Venue

Theory	Start	8:30	10:05	11:40	13:15	14:50
	End	10:00	11:35	13:10	14:45	16:20
MON	Theory	A11-CHY1005-LTP-AB-403		C11-CHY1005-LTP-AB-310 **(Practical)**		E-13-CHY1005-LTP-AB-410
TUE	Theory	D11-CHY1005-LTP-AB-304	E-11-CHY1005-LTP-AB-410			
WED	Theory	A12-CHY1005-LTP-AB-403		C12-CHY1005-LTP-AB-310		
THU	Theory	D12-CHY1005-LTP-AB-304	E-12-CHY1005-LTP-AB-410 **(Practical)**			
FRI	Theory	A13-CHY1005-LTP-AB-403 **(Practical)**		C13-CHY1005-LTP-AB-310		D13-CHY1005-LTP-AB-304 **(Practical)**

Module – 01
Introduction to Computational Chemistry

Overview of Computational Chemistry

➢ What is the **role and purpose** of computational chemistry? What does computational chemistry allow us to do that cannot be done using "traditional" (i.e. wet) chemistry?

➢ What is the **fundamental mathematical expression** that needs to be solved in doing computational chemistry? What are the terms in this equation, what are their significance, what variations can be used?

➢ What are the **approximations** that can be used in doing computational chemistry? What are the pros and cons of the various approximations? How does choice of approximation affect the results, the computing time, etc.

➢ There are roughly four different **methods** in computational chemistry: *ab initio methods, semi-empirical methods, density functional theory (DFT) and molecular mechanics/molecular dynamics.* What are these methods? How do they differ?

➢ What are the **fundamental units** of measure used by computational chemists? What are some different ways that these fundamental units might be expressed?

➢ What are some of the **computer codes** that one might use to do computational chemistry? What platforms are needed for these codes, what are the strengths and limitations of these codes?

➢ What kinds of problems can we solve?

➢ What kinds of tools can we use?

➢ What type of results we will get?

What is Chemistry?

Chemistry is **the branch of science that deals with the properties, composition, and structure of elements and compounds, how they can change, and the energy that is released or absorbed when they change**. So Chemistry is ***the study of matter and change***.

Traditionally, chemistry has been broken into five main sub-disciplines: Organic, Analytical, Physical, Inorganic and Biochemistry.

The term theoretical chemistry may be defined as the mathematical description of chemistry.

There are 02 ways to solve theoretical chemistry problems: -

✓ Computational theoretical chemistry
✓ Non-computational theoretical chemistry.

Computational theoretical chemistry is primarily deals with the numerical computation of molecular electronic structures and molecular interactions.

Non computational theoretical (quantum) chemistry deals with the formulation of analytical expressions for the properties of molecules and their reactions.

What is Computational Chemistry?

The term theoretical chemistry may be defined as the mathematical description of chemistry. The term computational chemistry is used when a mathematical method is sufficiently well developed that it can be automated (run) for implementation on a computer.
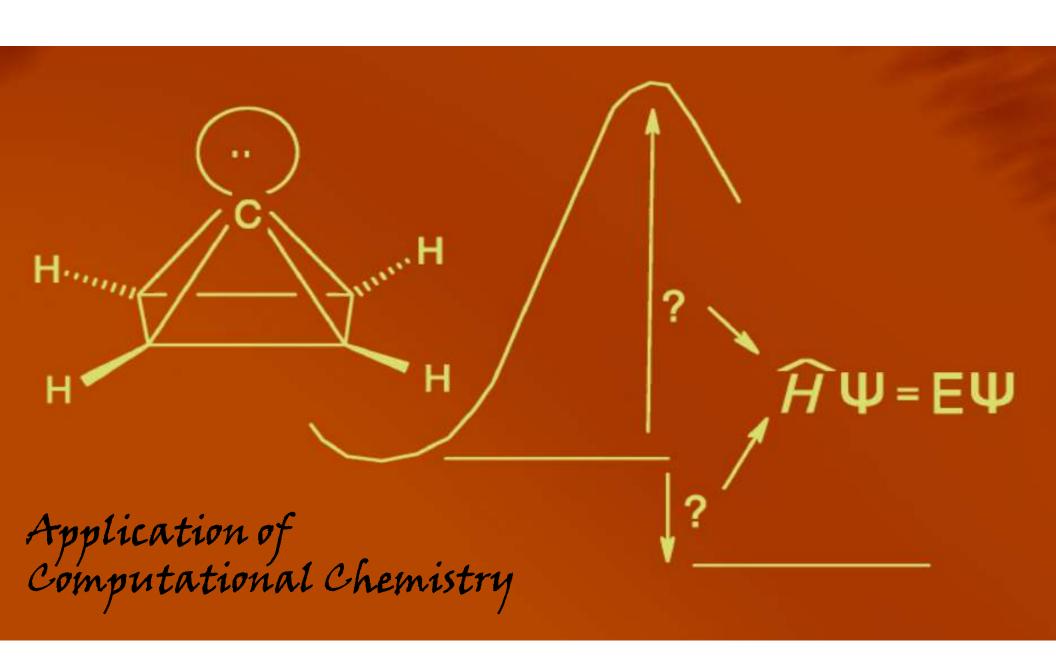
Computational chemistry is a branch of chemistry that uses computer simulation (Cloning, reproduction) to assist in solving chemical problems. It uses methods of theoretical chemistry, incorporated into computer programs, to calculate the structures and properties of molecules, groups of molecules, and solids.

Computational chemistry is the application of chemical, mathematical and computing skills to the solution of interesting chemical problems. It uses computers to generate information such as properties of molecules or simulated experimental results.

Very few aspects of chemistry can be computed exactly, but almost every aspect of chemistry has been described in a qualitative or approximate quantitative computational scheme/method.

Computational chemistry has become a useful way to investigate materials that are too difficult to find or too expensive to purchase. It also helps chemists make predictions before running the actual experiments so that they can be better prepared for making observations.

The quantum and classical mechanics, statistical physics and thermodynamics are the foundation for most of the computational chemistry theory and computer programs as they model atoms and molecules with mathematics.

Application of Computational Chemistry

Computational chemistry (also called *molecular modelling*) is a set of techniques for investigating chemical problems on a computer. Questions commonly investigated computationally are:

✓ **Molecular geometry:-**

Molecular geometry, also known as the **molecular structure**, is the three-dimensional structure or arrangement of atoms in a molecule. Understanding the molecular structure of a compound can help determine the **polarity, reactivity, phase of matter, color, magnetism, Shape of molecules - bond length, angles, dihedrals** (the angle between two planes, both of which pass through the same bond) as well as the **biological activity.**

✓ **Energies of molecules and transition states:-**

Helps in identifying which isomer is favored at equilibrium and from transition state and reactant energies we can predict how fast a reaction should go.

✓ **Chemical reactivity**

Enables us to predict where various kinds of reagents will attack a molecule. Helps in identifying electronic cloud i.e. where the electrons are concentrated (nucleophilic sites) and where they want to go (electrophilic sites).

✓ **IR, UV and NMR spectra:-**

IR, UV and NMR spectra:- Helps in calculating/interpreting the spectra of unknown molecule.

A1   Isomer- Same molecular formula but different spatial arrangement of atoms.
Admin, 10/31/2022

A2   Types- (1) Structural Isomerism (2) Steroisomerism
Admin, 10/31/2022

A3   Structural Isomerisim
Admin, 10/31/2022

A4   Structural Isomerism - Chain Isomerism, Position Isomerism, Functional Isomerism .
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A5   Stereoisomerism - Geometric isomerism (Cis & Trans), Optical Isomerism
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Tools of Computational Chemistry

The main tools of computational chemistry can be broadly classified into 05 types:-

1) Molecular Mechanics
2) Ab initio Method
3) Semi empirical Calculations
4) Density Function Theory (Method)
5) Molecular Dynamics

➤ Molecular Mechanics

Molecular mechanics is based on a model of a molecule as a collection of balls (atoms) held together by springs (bonds).

If we know the normal spring lengths and the angles between them, and how much energy it takes to stretch and bend the springs, we can calculate the energy of a given collection of balls and springs, i.e. of a given molecule.

Changing the geometry until the lowest energy is found enables us to do a geometry optimization, i.e. to calculate a geometry for the molecule. Molecular mechanics is fast: a fairly large molecule like a steroid (e.g. cholesterol, $C_{27}H_{46}O$) can be analyzed easily.

➢ Ab initio Calculations

Ab Initio calculations (ab initio, Latin: "from the start", i.e. from first principles") are based on the Schrödinger equation.

This is one of the fundamental equations of modern physics and describes among other things, how the electrons in a molecule behave. The ab initio method solves the Schrödinger equation for a molecule and gives us an energy and wave function.

The wave function (Ψ) is a mathematical function that can be used to calculate the electron distribution. From the electron distribution we can interpret how polar the molecule is, and which parts of it are likely to be attacked by nucleophiles or by electrophiles.

ab initio calculation is based only on basic physical theory (quantum mechanics) and is in this sense "from first principles".

➢ Semi empirical Calculations

Semi-empirical method means partially empirical (experimental). It involves various assumptions, approximations or generalization to simplify the calculations or produce/yield a result in accordance with the observations (experimental results).

Semi-empirical techniques use approximations from empirical (experimental) data to provide the input into the mathematical models.

Semi-empirical calculations are, like ab initio, based on the Schrödinger equation. In this method more approximations are made in solving it, and the very complicated integrals are not evaluated in semi-empirical calculations. This plugging of experimental values into a mathematical procedure to get the best calculated values is called **parameterization (or parametrization).**

Semi empirical method is the mixing of theory and experiment that makes the method "semi-empirical". It is based on the Schrödinger equation, but parameterized with experimental values.

➢ **Density Function Theory**

Density functional calculations (DFT calculations, density functional theory) are, like ab initio and semi-empirical calculations, based on the Schrödinger equation.

DFT does not calculate a conventional wave function, but rather derives the electron distribution (electron density function) directly.

Density functional calculations are usually faster than ab initio, but slower than semi empirical.

➢ **Molecular Dynamics**

Molecular dynamics calculations apply the laws of motion to molecules.

We can simulate the motion of an enzyme as it changes shape on binding to a substrate (surface), or the motion of a large group of water molecules around a molecule of solute.

Quantum mechanical molecular dynamics also allows actual chemical reactions to be simulated.

Errors in Computed Quantities

The study of chemistry is very important as its domain encompasses every sphere of life. Chemists study the properties and structure of substances and the changes undergone by them.

When the properties of a substance are studied, measurement is inherent. The quantification of properties requires a system of measurement and units in which the quantities are to be expressed.

Many systems of measurement exist, of which the English and the Metric Systems are widely used. The uniform and common system agreed throughout the world is SI Units (International System of Units).

Measurements involve recording of data, which are always associated with a certain amount of uncertainty, the proper handling of data obtained by measuring the quantities is very important.

Units of Measurement

The units of measurement are the collection of standard and other units that are used to measure various physical quantities.

For e.g. - Different units to measure the quantities like length, mass, volume, current, temperature, etc.

Base Units & Derived Units

Base Units			Derived Units		
Property	Unit	Symbol	Property	Unit	Symbol
Length	Meter	m	Frequency	Hertz	Hz
Weight	Kilogram	Kg	Power	Watt	W
Time	sec	S	Radian		θ
Temperature	Kelvin	K	Steradian		Ὠ
Electric Current	Ampere	Amp			
Luminous Intensity	Candela	Cd			
Amount of substance	Mole	mol			

STANDARD PREFIXES FOR THE SI UNITS OF MEASURE

Multiples	Name		deca-	hecto-	kilo-	mega-	giga-	tera-	peta-	exa-	zetta-	yotta-
	Symbol		da	h	k	M	G	T	P	E	Z	Y
	Factor	10^0	10^1	10^2	10^3	10^6	10^t	10^{12}	10^t	10^{18}	10^{21}	10^{24}

Multiples	Name		deca-	centi-	milli-	micro-	nano-	pico-	femto-	atto-	zetta-	yotta-
	Symbol		d	c	m	μ	n	p	f	a	z	y
	Factor	10^0	10^1	10^2	10^3	10^6	10^t	10^{12}	10^t	10^{18}	10^{21}	10^{24}

Conversion Units

Property	Atomic Unit	Conversion
Length	Bohr	1 Bohr = 0.529177249 A°
Weight	atomic mass unit (amu)	1 amu = $1.6605402 \times 10^{-27}$ kg
Charge	electron charge	1 electron = 1.602188×10^{-19} Coulombs
Energy	Hartree	1 Hartree = 27.2116 eV
Charge separation	Bohr electron	1 Bohr electron = 2.541765 Debye

Metrology and Measurements

Metrology is the science of measurement. It establishes a common understanding of units, crucial in linking human activities.

Metrology is "the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology,"

Computational Metrology means the study of how data analysis factor affects the measurement uncertainty of the system.

Decimal based metric system was adopted in 1795.

Equipment used in experimental Chemistry ranges from weighing balances & scale to Chromatography & Spectroscopies.

Significant Figures / Significant Digits

The concept of significant figure arises from use of measuring devices and equipment & their associated uncertainty.

For example- In India blood alcohol level of 0.08% is the cut-off for intoxication. How would interpret 0.0815/0.0799/0.0751? How the data is rounded depends on instrument and devices.

A figure of digit denotes any one of the ten numbers (0,1,2,3,4,5,6,7,8,9). A digit alone or in combination serves to express a number.

The uncertainty in the experimental or the calculated values is indicated by mentioning the number of significant figures. Significant figures are meaningful digits which are known with certainty plus one which is estimated or uncertain. The uncertainty is indicated by writing the certain digits and the last uncertain digit. Thus

Non-zero digits are always significant
Any zero between two significant digits are significant
A final zero / trailing zero in decimal portion only are significant.

For Example- **Non Zero digits are always significant**
26.32- Four Significant digits 7.94- Three Significant digits

Any Zero between two significant digits are significant
406- 4 & 6 are Significant digits, 0 is a significant figure

A final zero or trailing zero in decimal portion ONLY are significant
0.00500, 0.03040
0.000230, 0.0000002500
Non Significant Significant
5×10^{-3} **Non significant zero disappear**

Trailing Zero in whole number are not significant
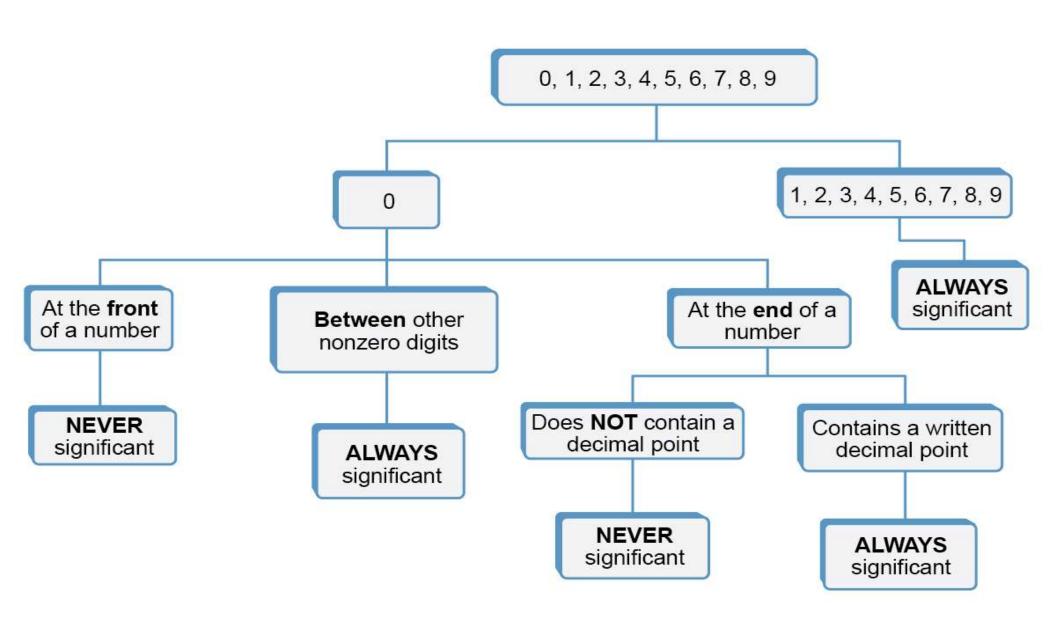
200- One Significant digits

2.0×10^2 Two Significant digits

2.01×10^2 Three Significant digits

25000- Two Significant digits

Leading Zero in whole number are not significant

00250- Two Significant digits

005.00×10^{-4} Three Significant digits

```
                        ┌─────────────────────────────┐
                        │  0, 1, 2, 3, 4, 5, 6, 7, 8, 9  │
                        └─────────────────────────────┘
                          │                           │
              ┌───────────┐                   ┌─────────────────────────┐
              │     0     │                   │ 1, 2, 3, 4, 5, 6, 7, 8, 9 │
              └───────────┘                   └─────────────────────────┘
```

0, 1, 2, 3, 4, 5, 6, 7, 8, 9

0

1, 2, 3, 4, 5, 6, 7, 8, 9

At the **front** of a number

Between other nonzero digits

At the **end** of a number

ALWAYS significant

NEVER significant

ALWAYS significant

Does **NOT** contain a decimal point

Contains a written decimal point

NEVER significant

ALWAYS significant

Rounding and Uncertainty (Error propagation)

In experimental chemistry quantitative measurements are performed & each measurement is associated with certain degree of uncertainty, no matter how careful and accurately measurements are done.

No measurement is complete without an accompanied statement of associated amount of uncertainty.

Computational analysis rely on reports that contain quantitative data from measurement results and decisions are directly impacted by errors introduced from the omission of measurement uncertainty.

The number of significant digits in the value provides only rough indication of its precision & the information is lost when rounding off occurs.

There are two types of uncertainties-
1) Absolute Uncertainty
2) Relative Uncertainty

Absolute Uncertainty- Measure of uncertainty with same units as reported value. For e.g.- The grape's width is 12.2+/-0.2 mm, where 0.2 mm is AU.

Relative Uncertainty- Represents absolute uncertainty as fraction (%). Use fraction during calculation. For e.g.- If you measure a pencil to be 10 cm +/- 1 cm then relative uncertainty is $1/10^{th}$ of its length. RU is **AU divided by measured value.**

Rules of Rounding measurement data

Identify the first two significant digits. Moving from left to right, the first non-zero number is considered to be first significant digit. Zeros ahead of decimal point is not considered as significant digit.

✓ When the digit which is to be retained is less than five or equal to 5, keep the retained figure unchanged.

For example: 2.441 becomes 2.4 to two significant figures.
**   2.5**41 becomes 2.5 to two significant figures.

✓ When the digit which is to be retained is greater than five, increase the retained figure by one.

For example: 2.653 becomes 2.7 to two significant figures.

✓ When the digit which is to be retained is even, leave it unchanged; conversely if the retained digit is odd, increase the retained figure by one (even/odd rounding).

For example: Thus, 3.450 becomes 3.4 but 3.3**50 becomes 3.4 to two significant figures**.

✓ When two or more figures are to the right of the last figure to be retained, consider them as a group in rounding decisions.

For example: 2.4(501), the group (501) is considered to be greater than 5 while for 2.5(499), (499) is considered to be less than 5.

Rounding Rules in terms of Insignificant Digit

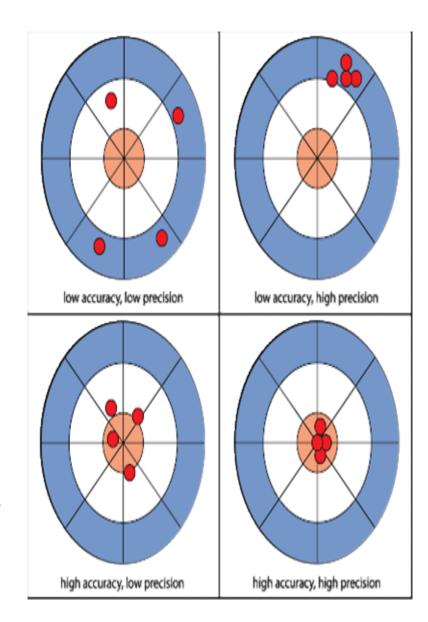| Rule Number	Insignificant Digit	Preceding Digit	Example (rounding off to two decimal places)
1	Insignificant digit to be dropped is more than 5	Preceding digit is raised by 1.	Number – 3.137 Result – 3.14
2	Insignificant digit to be dropped is less than 5	Preceding digit is left unchanged.	Number – 3.132 Result – 3.13
3	Insignificant digit to be dropped is equal to 5	If preceding digit is even, it is left unchanged.	Number – 3.125 Result – 3.12
4	Insignificant digit to be dropped is equal to 5	If preceding digit is odd, it is raised by 1.	Number – 3.135 Result – 3.14

Accuracy & Precision

There are two contributors to Absolute Uncertainty-
1) Accuracy   2) Precision

Accuracy refers to the closeness of a measured value or standard or known value.
For example- In lab we obtain a weight measurement of 8 kg of a given substance and actual is 5 kg then measurement is not accurate.

Precision refers to the closeness of two or more measurements to each other.
For example- In lab if we obtain a weight of given substance 8 kg each time then measurement is not precise.

low accuracy, low precision

low accuracy, high precision

high accuracy, low precision

high accuracy, high precision

Precision is independent of accuracy i.e. One can be precise but inaccurate or accurate but imprecise.

Errors & its types

The difference between exact/known value and measured value/approximate value.
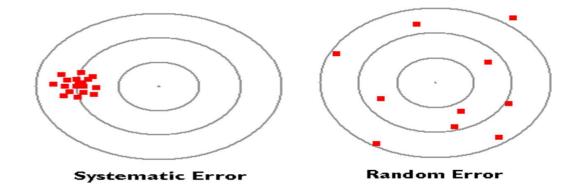
Errors = Actual Value – Measured Value

Errors represents the deviation from the accuracy or correctness

Errors in chemistry do not represent mistakes but they represent uncertainty in the results of measurement.

Errors can be of two types:
1) **Systematic Error**
2) **Random Error**

Systematic Error   Random Error

Systematic Errors or Bias

A **systematic error** is caused by a defect in the analytical method or by an improperly functioning instrument or analyst.

A procedure that suffers from a systematic error is always going to give a mean value i.e. different from the true value. The term 'bias' is sometimes used when defining and describing a systematic error.
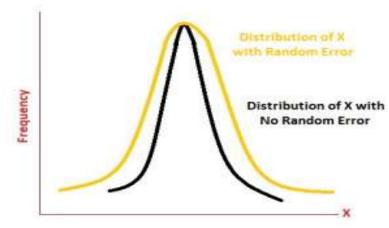
Systematic errors tend to be consistent in magnitude and/or direction. If the magnitude and direction of the error is known, accuracy can be improved by additive or proportional corrections.

Systematic errors may be due to instrumental errors, environmental errors, theoretical errors and observational errors.

Random Errors

Random errors are unavoidable. They are unavoidable due to the fact that every physical measurement has limitation, i.e. some uncertainty.

Random errors are caused by the sudden change in experimental conditions, noise and tiredness in the working persons. These errors are either positive or negative.
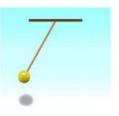
For example- The random errors due change in humidity, unexpected change in temperature, fluctuation in voltage and malfunctioning of software. **These errors may be reduced by taking the average of a large number of readings.**

Errors Analysis

1

For example, suppose you measure the oscillation period of a pendulum with a stopwatch five times.

Trial no (i)	1	2	3	4	5
Measured value (X_i)	3.9	3.5	3.6	3.7	3.5

2

The average of all the five readings gives the most probable value for time period.

$$\overline{X} = \frac{1}{n} \sum X_i$$

$$\overline{X} = \frac{3.9 + 3.5 + 3.6 + 3.7 + 3.5}{5} = \frac{18.2}{5}$$

$$\overline{X} = 3.64 = 3.6$$

3

The magnitude of the difference between mean value and each individual value is called absolute error.

$$\Delta X_i = |\overline{X} - X_i|$$

The absolute error in each individual reading:

X_i	3.9	3.5	3.6	3.7	3.5
ΔX_i	0.3	0.1	0	0.1	0.1

4

The arithmetic mean of all the absolute errors is called mean absolute error.

$$\Delta \overline{X} = \frac{1}{n} \sum \Delta X_i$$

$$\Delta \overline{X} = \frac{0.3 + 0.1 + 0 + 0.1 + 0.1}{5} = \frac{0.6}{5}$$

$$\Delta \overline{X} = 0.12 = 0.1$$

- The most common way adopted by scientist and engineers to report a result is:

> Result = best estimate $\pm$ error

- It represent a range of values and from that we expect a true value fall within.

- Thus, the period of oscillation is likely to be within (3.6 ± 0.1) s.

The relative error is defined as the ratio of the mean absolute error to the mean value.

> relative error = $\Delta \bar{X} / \bar{X}$

$$\Delta \bar{X} / \bar{X} = \frac{0.1}{3.6} = 0.0277$$
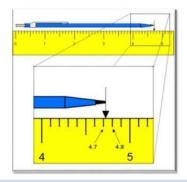
$$\Delta \bar{X} / \bar{X} = 0.028$$

The relative error multiplied by 100 is called as percentage error.

> percentage error = relative error $\times$ 100

percentage error = 0.028 $\times$ 100

percentage error = 2.8 %

Least count error is the error associated with the resolution of the instrument.

- The least count error of any instrument is equal to its resolution.

- Thus, the length of pen is likely to be within (4.7 ± 0.1) cm.

Combination of Errors

In different mathematical operations like addition, subtraction, multiplication and division the errors are combined according to some rules.

- Let ΔA be absolute error in measurement of A
- Let ΔB be absolute error in measurement of B
- Let ΔX be absolute error in measurement of X

When X = A ± B

When X = A^n

$$\frac{\Delta X}{X} = \frac{\Delta A + \Delta B}{A \pm B}$$

$$\frac{\Delta X}{X} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$$

$$\frac{\Delta X}{X} = n\frac{\Delta A}{A}$$

$$\Delta X = \Delta A + \Delta B$$

$$\Delta X = \left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right)X$$

$$\Delta X = n\frac{\Delta A}{A}X$$

Standard Deviation & Standard Error of the mean

- The standard deviation is a statistic that measures the dispersion of a dataset relative to its mean and is calculated as the square root of the variance.
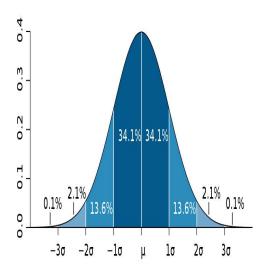
$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

σ = population standard deviation

N = the size of the population

x_i = each value from the population

μ = the population mean

The standard error of the mean (SEM) can be expressed as:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

where

σ is the standard deviation of the population.

n is the size (number of observations) of the sample.

Exercise

1) The marks of a class of eight students (that is, a statistical population) are the following eight values: 2, 4, 4, 4, 5, 5, 7, 9. Calculate mean, absolute error, mean absolute error, relative error, percentage error, variance, standard deviation, and standard error.

History of Computational Chemistry

Several papers were published detailing the use of computers in chemistry during the 1960s and 1970s.

Molecular Design, Ltd. (1978) and Tripos Associates, Inc. (1979) were the first two companies who address the new areas of chemical databases and molecular modeling respectively.

The development of computational chemistry is mentioned in terms of research publications by various researchers since 1925.

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Year	Publications/Software & Hardware/Companies	Details
1925	Publication	Heisenberg publishes his first paper on quantum mechanics (Z. Phys., 1925, 33, 879).
1926	Publication	Schrödinger publishes his first paper on the theory of quantum mechanics (Ann. Phys., 1926, 79, 361).
1931	Publication	Pi electron theory postulated by Hückel (Z. Phys., 1931, 70, 204).
1943	Software & Hardware	The first computer, the ENIAC (Electronic Numberical Integrator and Computer) is built for the US Army Ordance Department.
1950	Publication	Roothaan publishes the description of the linear combination of atomic orbitals - molecular orbital - self consistent field (LCAO-MO-SCF) method.
1951	Software & Hardware	The first UNIVAC (Universal Automatic Computer) is delivered to the Census Bureau
1953	Publication	Metropolis and co-workers describe the application of the Monte Carlo method of simulation to physical chemistry problems (J. Chem. Phys., 1953, 1087, 21).
1955	Publication	Scherr reports the first ab initio calculation for a large system, N2.
1957	Publication	Pople publishes details on the application of self-consistent molecular orbital methods to pi electrons (J. Phys. Chem., 1957, 61, 6).

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1958	Software & Hardware	The first integrated circuit board is constructed by Jack Kilby at Texas Instruments.
1961	Publication	Hendrickson publishes the results of calculations of relative conformational stabilities of cyclohexane (J. Amer. Chem. Soc., 1961, 83, 5537).
1963	Software & Hardware	Quantum Chemistry Program Exchange (QCPE) formed at Indiana University to distribute quantum chemistry codes.
1964	Publication	Hansch and Fujita describe a new approach to analyzing drug actions: QSAR, a quantitative structure activity relationship (Hansch, C and Fujita, T., J. Amer. Chem. Soc., 1964, 86, 1616)
1965	Publication	The Morgan algorithm is published (Morgan, H.L., "The Generation of Unique Machine Description for Chemical Structures - A Technique Developed at Chemical Abstracts Services", J. Chem. Doc., 1965, 5, 107-113)
1966	Publication	Cyrus Levinthal, et. al. publish paper on the use of molecular graphics and computer simulation (Levinthal, C.; Scientific American, 1966, 214: 42)
1969	Publication	1) E.J. Corey and Todd Wipke publish details for the Computer-Assisted Organic Synthesis Planning (CASP) program (Corey, E.J.; Wipke, W.T.; Science, 1969, 166: 178). 2) Levitt and Lifson report the use of force fields to refine protein conformations derived from experimental data (Michael Levitt and Shneior Lifson; J. Mol. Biol., 1969, 46, 269-279).

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1970	Publication	Warshel and Lifson publish a description of the Consistent Force Field (Warshal, A.; Lifson, S.; J. Chem. Phys., 1970, 53: 582-594).
1971	Publication	Hendrickson describes a computer assisted synthesis program (Hendrickson, J.B., J. Amer. Chem. Soc., 1971, 93, 6847).
1972	Software & Hardware	Ray Tomlinson releases details about a new computer program that can send and receive personalized messages. *Electronic mail is born!*
1973	Publication	1) N.L. Allinger describes the modeling of hydrocarbons with a new force field, MM1 (Allinger, N.L.; Sprague, J.T.; J. Amer. Chem. Soc., 1973, 95: 3893) 2) Robert Metcalfe receives his Ph.D. from Harvard University. His thesis describes Ethernet
1974	Publication	1) Robert Langridge, et. al. publish paper on the use of computer graphics to visualize 3-D chemical structures (Langridge, R.; Fed. Proc. Fed. Am. Soc. Exp. Biol., 1974, 33: 2332). 2) Vint Cerf and Robert Kahn develop the concept of connecting networks of computers into an "internet" and develop the Transmission Control Protocol (TCP).
1975	Company	1) Microsoft is founded by Bill Gates and Paul Allen. 2) The CONGEN program for automated structure generation is described (Carhart, R.E., Smith, D.H., Brown, H., Djerassi, C., J. Amer. Chem. Soc., 1975, 97, 5755)
1977	Publication	Martin Karplus, et. al. publish the first molecular dynamics study of a protein (McCammon, J.A.; Gelin, B.R.; Karplus, M.; Nature, 1977 267: 585-590).

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1978	Software & Hardware	National Resource for Computation in Chemistry (NRCC) established at Lawrence Berkeley National Laboratory, led by Bill Lester
1980	Publication Software & Hardware	1) Wüthrich et. al. publish paper detailing the use of multi-dimensional NMR for protein structure determination (Kumar, A.; Ernst, R.R.; Wüthrich, K.; Biochem. Biophys. Res. Comm., 1980, 95: 1). 2) The first issue of the Journal of Computational Chemistry is published. 3) General Atomic and Molecular Electronic Structure System (GAMESS) developed at NRCC by Michel Dupuis and co-workers
1981	Publication	1) Peter Kollman, et. al. publish preliminary description of the AMBER force field for protein/DNA calculations. (Weiner, P.K.; Kollman, P.A.; J. Comp. Chem., 1981, 2: 287-303). 2) IBM introduces its Personal Computer to the market.
1982	Publication	An algorithm for docking small molecules to receptors (later to become the DOCK program) is published by Irwin Kuntz and colleagues (Kuntz, I.D.; Blaney, J.M.; Oatley, S.J.; Langridge, R.; Ferrin, T.E.; J. Mol. Biol., 1982, 161, 269).
1983	Publication Software & Hardware	1) Martin Karplus, et. al. publish description of the CHARMM program (Brooks, B.R.; Bruccoleri, R.E.; Olafson, B.D.; States, D.J., Swaminathan, S. and Karplus, M.; J. Comp. Chem., 1983, 4: 187-217). 2) W. F. van Gunsteren, et. al. publish description of molecular dynamics of proteins using GROMOS program (van Gunsteren, W.F.; Berendsen, H.J.C.; Hermans, J.; Hol, W.G.J.; Postma, J.P.M.; Proc. Natl. Acad. Sci., 1983, 80: 4315) 3) The Compact Disk (CD) is launched.

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1984	Publication	The Macintosh is announced.
1986	Company	Biosym Technologies announces the first computational chemistry consortium to derive potential energy functions.
1987	Publication	The Journal of Computer-Aided Molecular Design is published.
1988	Software & Hardware	A new program, an Internet computer virus designed by a student, infects 6,000 military computers in the US.