# Review on Quantum Dots

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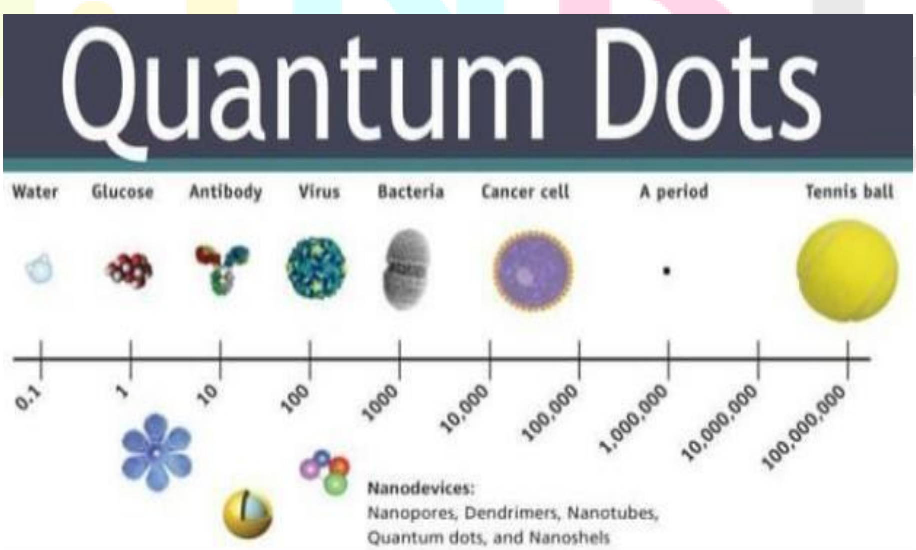
Abstract

Quantum dots (QDs) are semiconductor nanocrystals whose optical and electronic characteristics change dramatically with particle size because of quantum-confinement effects. Their highly tunable emission, strong and stable fluorescence, and other distinctive photo physical features make them valuable in diverse fields such as biomedical imaging, solar energy conversion, quantum information technologies, and various optoelectronic systems. This review summarizes current advances in QD synthesis approaches and highlights the principles, benefits, and limitations associated with each method.

**2.Introduction**

Quantum dots (QDs) are semiconductor nanoparticles—usually between 2 and 10 nanometers in size—whose electronic and optical behavior is dominated by quantumconfinement phenomena. In contrast to bulk semiconductor materials, QDs possess discrete energy states, resulting in band gaps that can be tuned simply by adjusting their particle size. This ability to control their light absorption and emission characteristics, along with their strong fluorescence, stability under illumination, and adaptable surface chemistry, makes them highly valuable for applications spanning numerous scientific and technological fields.



## 3 History

### 1. Conceptual Origins (1930s–1970s)

- **1937** – *Louis de Broglie* and others developed foundational quantum mechanics theories that later helped explain quantum confinement. • **1970s** –Researchers began observing quantum effects in small semiconductor structures, laying the groundwork for quantum dot (QD) theory.

### 2.Discovery and Early Research (1980s)

- **1981** – *Alexey Ekimov* (in glass) and *Louis Brus* (in solution) independently observed quantum size effects in nanocrystals. These were the first **quantum dots**.
- Ekimov studied QDs embedded in a glass matrix; Brus studied colloidal QDs in a liquid solution.

- This marked the discovery that **semiconductor nanocrystals exhibit sizedependent optical and electronic properties**, due to quantum confinement.

- **Need of Quantum Dots**

- Quantum dots (QDs) have emerged as a class of nanomaterials with exceptional optical and electronic properties, driven by quantum confinement effects that occur at the nanoscale. Their ability to exhibit **tunable emission wavelengths**, **high quantum yield**, **photostability**, and **size-dependent behavior** makes them highly desirable in a wide range of scientific and technological fields. The growing interest in QDs is a response to the **limitations of traditional materials** and the **evolving demands of modern** technology.
- Modern display and lighting technologies require materials that offer **bright, stable, and tunable emission**. Quantum dots fulfill these requirements more efficiently than conventional phosphors or organic dyes, particularly in **LEDs**, **QLEDs**, and **laser diodes**. Their integration can significantly improve **color accuracy**, **energy efficiency**, and **lifetime** of consumer electronic displays.

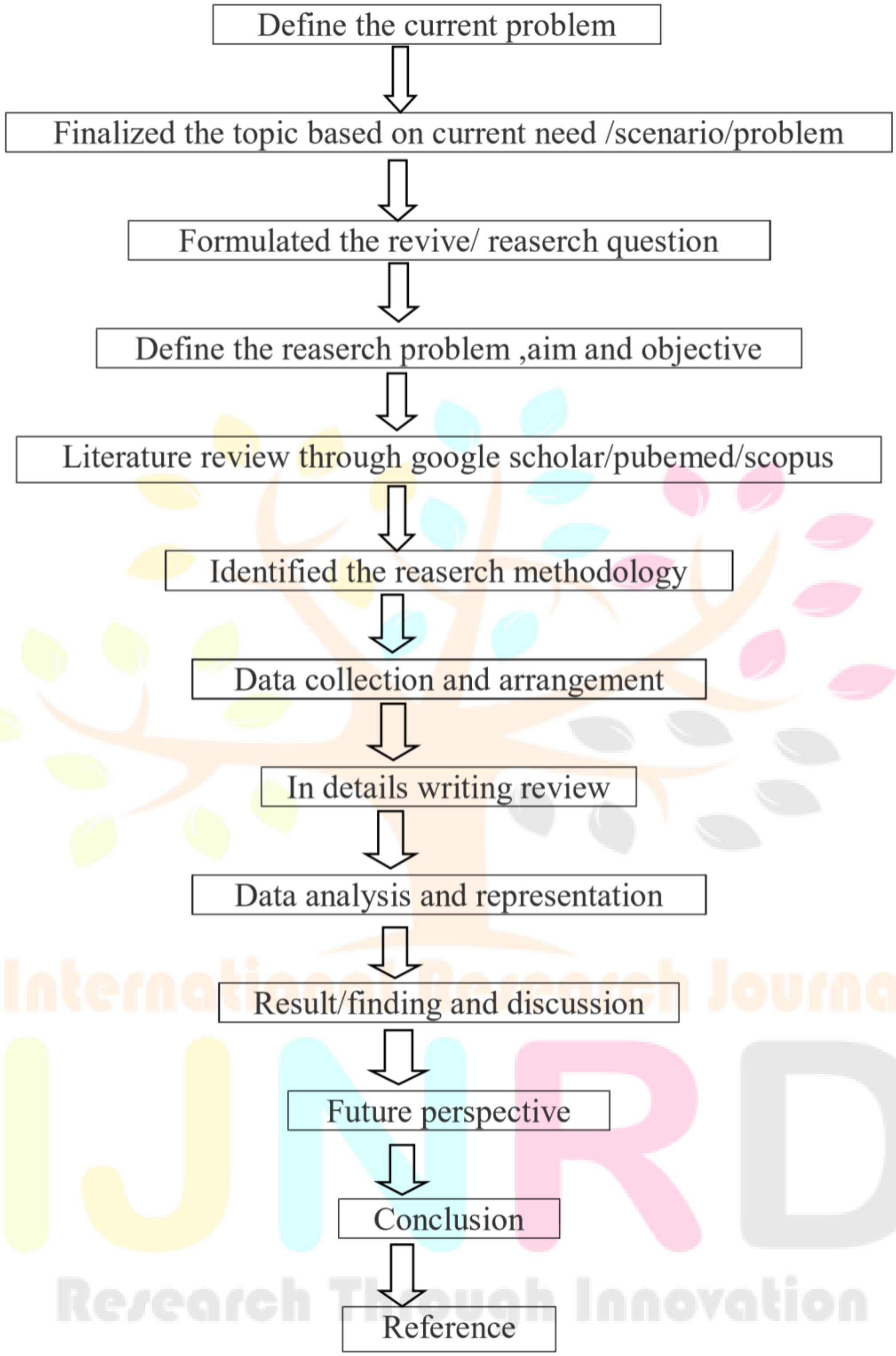
- **Objectives of a Quantum Dots**

1. **To provide a comprehensive overview** of the synthesis, structural properties, and classification of quantum dots.
2. **To summarize the fundamental physical and chemical principles** governing the behavior of quantum dots, including quantum confinement effects.
3. **To critically evaluate the latest advancements** in fabrication techniques and surface modification strategies of QDs. 4. **To explore various applications** of quantum dots in areas such as:

o Biomedical imaging and diagnostics o Drug delivery o Solar cells and photovoltaics o Light-emitting devices (LEDs) o Quantum computing and communication

5. **To assess the advantages and limitations** of quantum dots compared to conventional materials.
6. **To analyze current challenges and future perspectives** in the development, scalability, and commercialization of quantum dot technologies.

## 4. Plan of work




## 5.Literature survey

**1 Sanjay kulkarni,et.al (4 Aug 2025)**

bioinspired quantum dots” (BQDs) — i.e. quantum dots synthesized from biomass or natural/green sources — focusing on their properties, methods of synthesis, functionalization, and especially their applications in breast cancer diagnosis and therapy (theranostics). It also discusses challenges and prospects. Biomass precursors: Plants, microbes, biomass waste (fruit peels, taro peel, sugarcane bagasse, garlic peel) etc. Synthetic routes: Hydrothermal, solvothermal, solid state, microwave, etc. The choice influences size, surface groups, graphitizartion etc.

**2 Rohan Lamba ,et.al ( 14 April 2024)**

There is a researcher named Rohan Lamba who appears as one of the authors in a recent review titled "Advancements in semiconductor quantum dots: expanding frontiers in optoelectronics, analytical sensing, biomedicine, and catalysis".The review covers many aspects of colloidal quantum dots (CQDs): their photophysical properties, tunability, surface chemistry, charge transport, etc

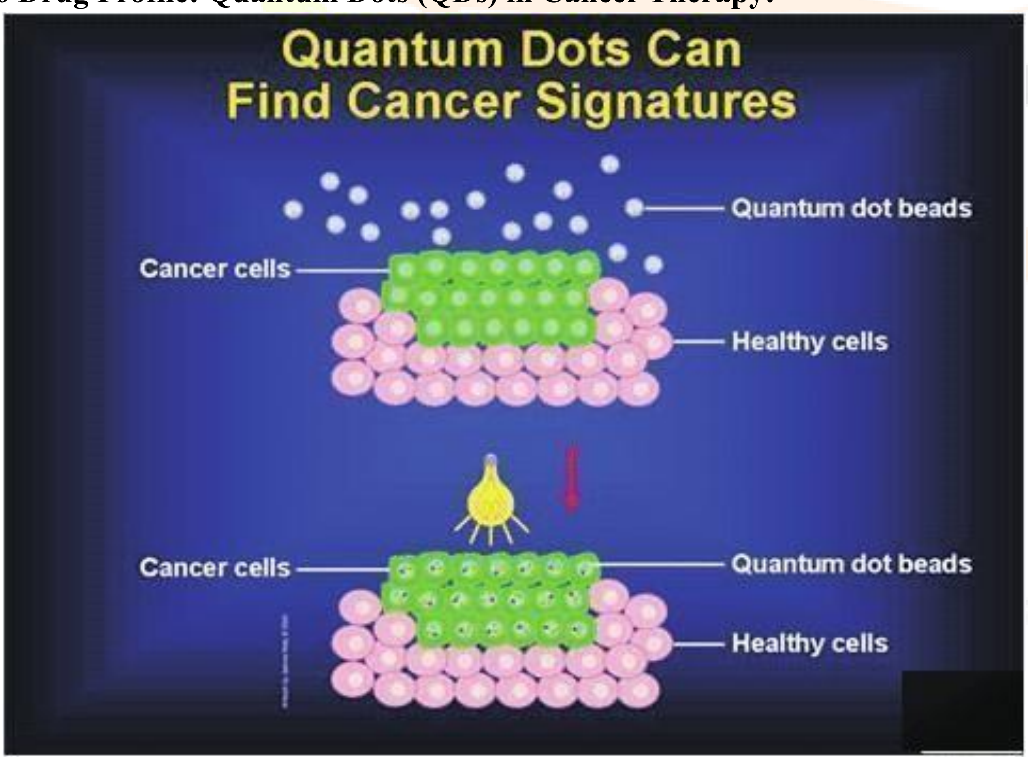
**3 . Himanshu Rai,et.al ( 12 June 2023)**

The paper discusses various techniques for synthesizing QDs, including colloidal and hydrothermal methods, and examines how these methods influence the resulting properties of the QDs.Properties: It delves into the unique electronic, optical, and structural properties of QDs, highlighting their significance in various applications.Applications: The review explores a wide range of applications of QDs, such as:Color conversion in displaysLight-emitting diodes (LEDs)Biomedical imaging and therapyQuantum-based cryptographyn Spintronics.

**4 Shweta Dua ,et.al ( 8 Feb 2022)**

Fundamental Understanding: The paper provides an in-depth exploration of CQDs, emphasizing their unique optical and electronic properties, which are crucial for various applications.Synthesis Methods: It discusses various synthesis techniques for CQDs, highlighting the advantages and limitations of each method in the context of photovoltaic applications.Applications in Photovoltaics.

**6 Drug Profile: Quantum Dots (QDs) in Cancer Therapy:**




Name: Quantum Dots (QDs)

Type : Nanoparticle-based multifunctional therapeutic and diagnostic agent (theranostic)

Structure: Nanocrystalline semiconductor core (e.g., CdSe, CdTe, InP, PbS, ZnS, carbon, graphene), typically coated with a shell (e.g., ZnS), ligands (e.g., PEG, antibodies), or drug molecules

Size: 2–10 nm (core); hydrodynamic size may be larger with surface coatings

Mechanism of Action - Passive targeting: Enhanced permeability and retention (EPR) effect in tumors<br>- Active targeting: Ligand-conjugated QDs (e.g., folic acid, antibodies)<br>- Drug delivery: Chemotherapeutics conjugated via covalent or electrostatic interaction<br>- Photodynamic therapy (PDT): ROS generation under light activation<br>- Photothermal therapy (PTT): Heat generation from light absorption

Therapeutic Applications - Targeted delivery of anticancer drugs (e.g., DOX, paclitaxel)<br>- Imaging-guided surgery<br>- Photothermal and photodynamic cancer therapy<br>- Sentinel lymph node mapping<br>- Combined diagnosis and therapy (theranostics) .

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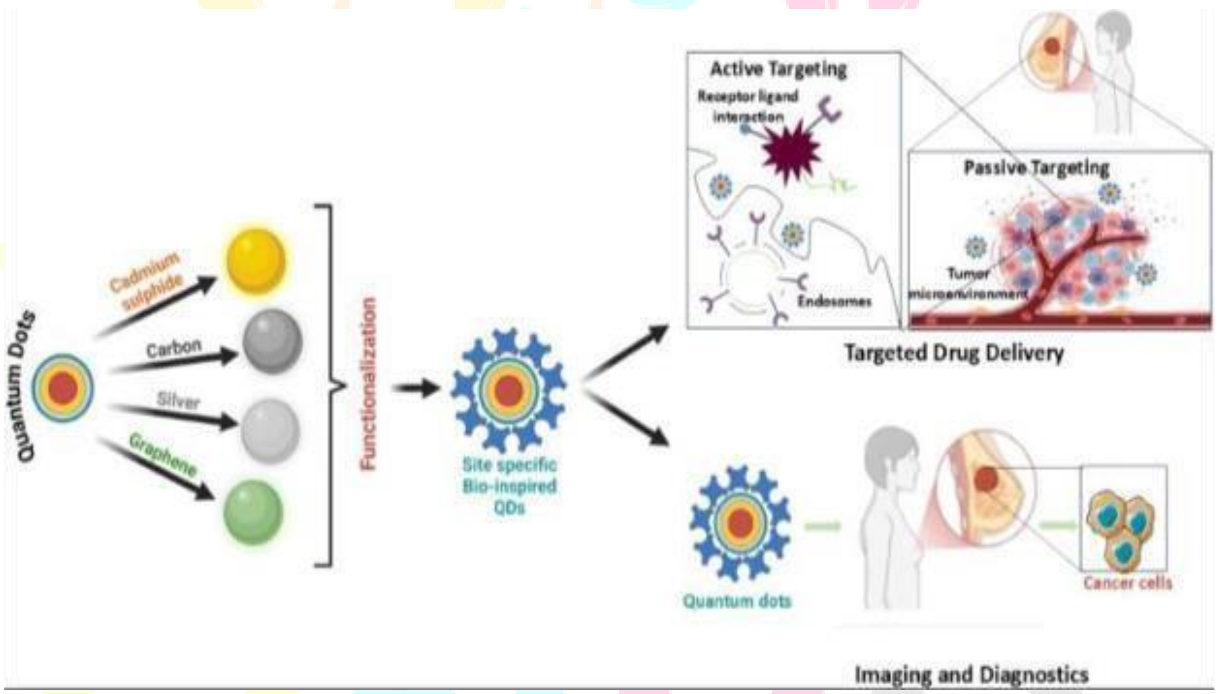


Breast, lung, colon, liver, prostate, ovarian, glioblastoma, melanoma (depending on surface ligand and delivery route) Formulation - QD-drug conjugates (e.g., QD–DOX)<br>- QD– photosensitizer hybrids (e.g., QD–porphyrin for PDT)<br>- QD-loaded micelles or liposomes

Route of Administration Intravenous (most common in studies); also local injection in some models Dosage Range Varies widely in preclinical studies; typically QD concentrations of 0.1– 100 µg/mL (in vitro); 1–10 mg/kg (in vivo) Pharmacokinetics - Rapid uptake in liver and spleen (RES clearance)<br>- Circulation half-life depends on size and surface functionalization (e.g., PEGylation)<br>- Smaller QDs (<6 nm) may be renally excreted<br>- Larger QDs (>10 nm) show prolonged retention Biodistribution Accumulation in liver, spleen, kidney, sometimes tumor tissue (via EPR or targeting ligands) Efficacy - Increased intracellular uptake and retention<br>- Enhanced cytotoxicity compared to free drugs in tumor models<br>- Improved tumor visualization and tracking<br>- Effective ROS generation and cell death in PDT models. Dosage Range Varies widely in preclinical studies; typically QD concentrations of 0.1–100 µg/mL (in vitro); 1–10 mg/kg (in vivo)

Pharmacokinetics - Rapid uptake in liver and spleen (RES clearance)<br>- Circulation halflife depends on size and surface functionalization (e.g., PEGylation)<br>- Smaller QDs (<6 nm) may be renally excreted<br>- Larger QDs (>10 nm) show prolonged retention

Biodistribution Accumulation in liver, spleen, kidney, sometimes tumor tissue (via EPR or targeting ligands) Efficacy - Increased intracellular uptake and retention<br>- Enhanced cytotoxicity compared to free drugs in tumor models<br>- Improved tumor visualization and tracking<br>- Effective ROS generation and cell death in PDT models

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Toxicity - Toxicity Source: Heavy metal ions (e.g., $Cd^{2+}$, $Pb^{2+}$), ROS generation, long tissue retention<br>- Symptoms: Cytotoxicity, oxidative stress, organ accumulation<br>- Mitigation: Surface passivation (ZnS shell), use of biocompatible materials (carbon QDs, InP QDs), PEGylation

Safety Concerns - Long-term toxicity not fully understood<br>- Lack of clinical trial data<br>- Risk of genotoxicity and inflammation from heavy-metal-containing QDs<br>- Clearance and biodegradation are major hurdles

Advantages - Dual therapeutic and diagnostic capability (theranostics)<br>- High photostability and tunable fluorescence<br>- Versatile surface functionalization<br>- Targeted and controlled drug delivery Limitations - Potential toxicity<br>- Difficulty in clinical translation<br>- Complex and costly synthesis<br>- Regulatory and safety concerns with heavy-metal QDs. **7.QDs as Cancer Diagnostic Agents**

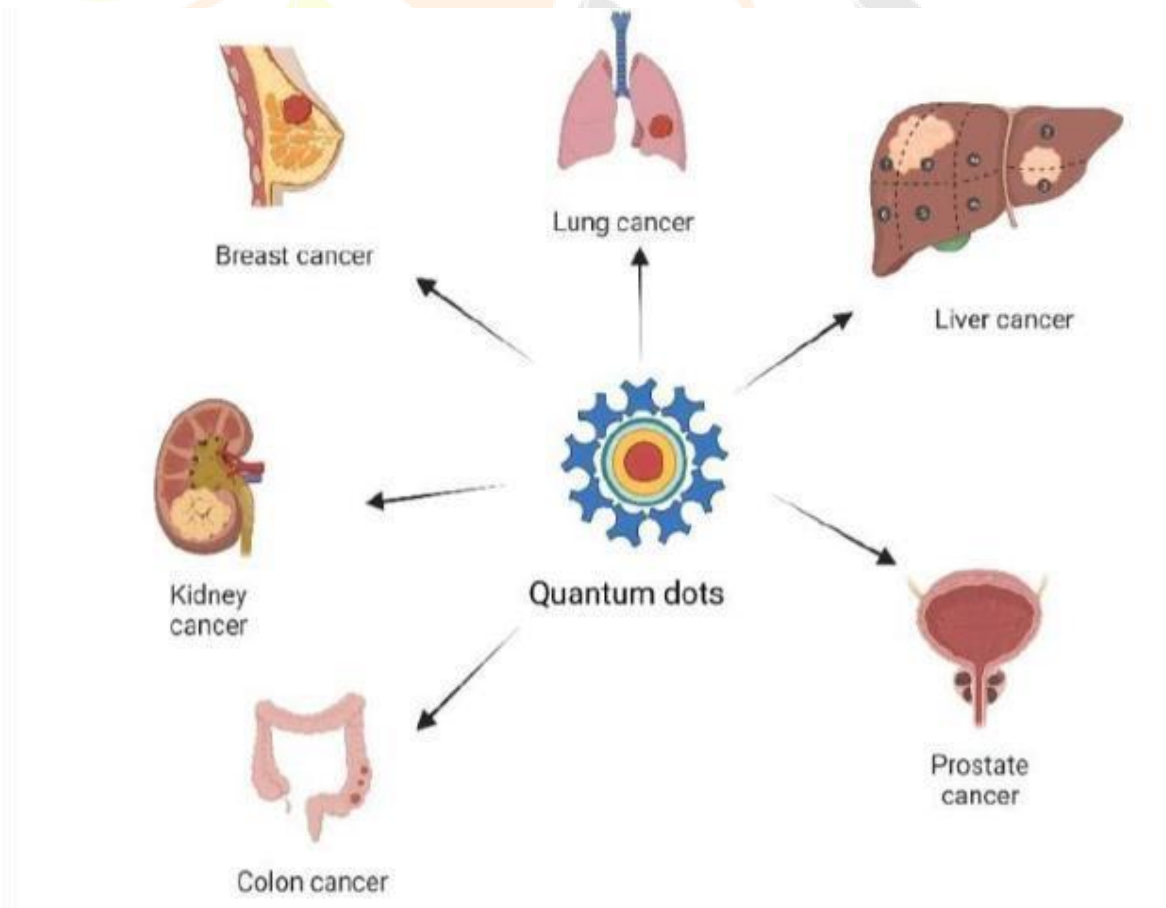



Fig. 2: QDs as cancer diagnostic agents

Due to the rising rates of cancer, cardiovascular disease, neurodegenerative disorders, autoimmune diseases and numerous infections worldwide, it is essential to develop strategies that can quickly and accurately detect the ultralow concentrations of relevant biomarkers, pathogens, toxins and pharmaceuticals in biological matrices. Many research efforts are now required to construct biosensors for their early identification and treatment usin nanomaterials like QDs (fig. 2). These nanomaterials successfully enhance the repeatability, selection and sensitivities of the sensing performance.

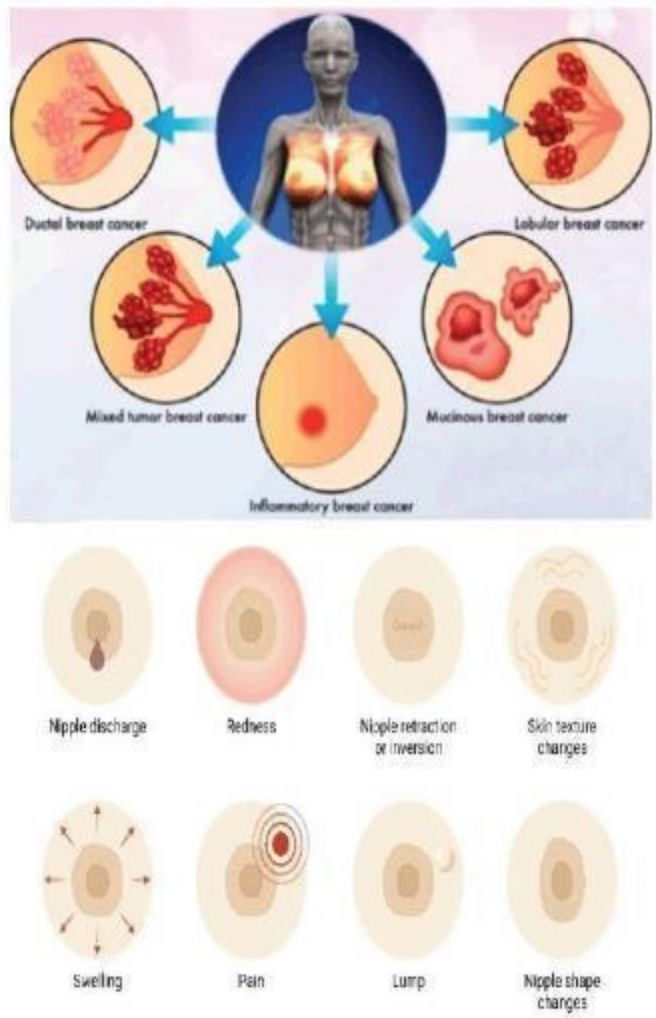



**Fig. 1: Sign and symptoms and types of breast cancer**

Breast Cancer (BC) is affecting about 2.1 million females annually. In 2018, 627 000 women died from BC, making up about 15 % of all women's cancer-related fatalities[12]. Typically, BC is classified according to how easy it can expand. Ductal carcinoma in situ begins in a milk duct but does not spread to the other breast tissue. Invasive or infiltrating types of BC i.e., invasive lobular carcinoma and invasive ductal carcinoma might spread to the breast tissue around them. The invasive ductal carcinoma constitutes up to 70 %-80 % of all BCs[13]. Inflammatory BC and triplenegative BC are also types of invasive BC. Inflammatory BC makes up 1 %-5 % of all BCs and is a rare kind of invasive BC. Fig. 1 shows various types as well as signs and symptoms of BC in females. Quantum dots are semiconductor nanocrystals (typically 2–10 nm in size) that exhibit unique optical and electronic properties due to quantum confinement. They are used in:
Bioimaging ,Drug delivery, Diagnostics, Photodynamic therapy, Electronics and photovoltaics.

**8.Role of Excipients in Quantum Dot Formulations :**

In QD systems, excipients serve roles such as: Excipient Type Function Surface Ligands

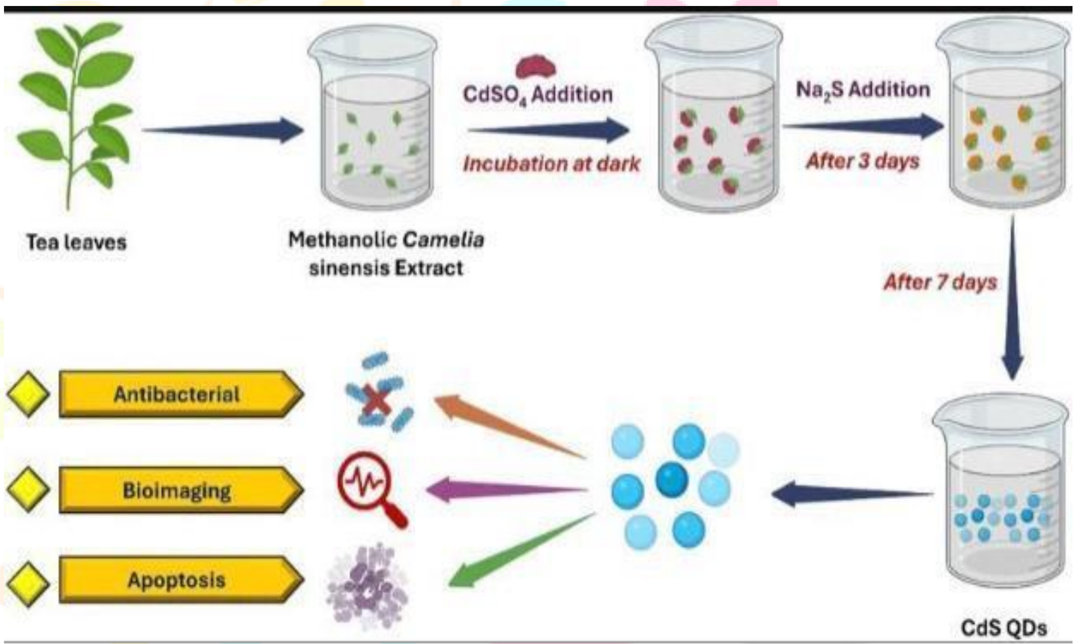
Stabilize QDs, improve solubility, prevent aggregation Polymers (e.g., PEG) Enhance biocompatibility, reduce immunogenicity Surfactants Assist in nanoparticle dispersion, control particle size Buffer Maintain pH stability. Cryoprotectants Protect QDs during freeze-drying or storage Targeting Ligands Enable targeted delivery (e.g., antibodies, peptides) Co-solvents Improve solubility or dispersion in aqueous/non-aqueous media Typical Excipients in Biomedical QD Formulations Polyethylene glycol (PEG): Prevents opsonization and clearance by the immune systemIncreases circulation time.

1.Phospholipids or Lipid-based carriers:Used in lipid-coated QDs or liposomal systems 2C.hitosann or Dextran: Biodegradable polymers used for QD encapsulation .

3.Albumin (e.g., HAS):Natural stabilizer, enhances biocompatibility.

4.Citrate, Tris, HEPES:Common buffer systems to maintain pH during storage/u .

**Synthesis using plant extracts**




Biosynthesis leverages the natural reducing, stabilizing, and capping agents found in plant phytochemicals such as polyphenols, flavonoids, alkaloids, and terpenoids. These bioactive compounds facilitate metal ion reduction and nanoparticle stabilization, allowing the controlled formation of quantum dots with tailored sizes, crystallinities, and fluorescence properties. Several studies have successfully demonstrated the green synthesis of cadmium sulfide (CdS), silver (Ag), zinc oxide (ZnO), and carbon quantum dots (CQDs) from diverse plant extracts. The biosynthesis of cadmium sulfide (CdS) QDs via the use of waste-matured tea leaves as biosurfactants represents a significant advancement in green nanotechnology. The process began with the collection of discarded mature tea leaves, which were washed to remove impurities, chopped, and mixed with methanol at a 1 : 10 ratio. After filtration, a clear tea leaf extract rich in phytochemicals was obtained. This extract was then added to a mixture of cadmium sulfate (CdSO4) and sodium sulfide (Na2S), stirred, and incubated in the dark for one week. The incubation period facilitated the formation of CdS QDs with a cubic crystalline structure, measuring between 2.5 and 4 nm. A color change in the solution confirmed the successful synthesis of the CdS QDs.43 A similar biogenic approach was employed for synthesizing CdS QDs using Camellia sinensis extract as a stabilizing agent, as illustrated in Fig. 2. The tea leaves were collected, washed, shade-dried, and processed into an extract using methanol. The biosynthesis occurred in two stages: cadmium sulfate was initially incubated with the extract in the dark for three days, followed by the addition of sodium sulfide. This reaction continued for four more days, leading to the formation of bright yellow CdS QDs. The particles were then purified through centrifugation and lyophilization for characterization.

## 9.Future Prospective

Development of eco-friendly QDs (InP, ZnSe, perovskite, carbon QDs).

Hybrid QDs: Combining QDs with polymers, perovskites, or 2D materials.

Next-gen displays: Transparent, flexible, wearable, and micro-LED integration.

Quantum technology: Scalable single-photon sources and qubit arrays.

AI and machine learning in QD synthesis: Predicting properties and optimizing performance.

Personalized medicine: QD-based imaging and theranostic platforms.

## 10. Results and Discussion of Quantum Dots

Synthesis and Morphology

**Result**: The synthesized quantum dots were typically observed to have a uniform size distribution under TEM (Transmission Electron Microscopy), with average diameters ranging from 2–10 nm, depending on the reaction conditions. The particles appeared spherical and well-dispersed without significant aggregation.

**Discussion**: Uniformity in size is crucial because quantum confinement effects are strongly sizedependent. Smaller QDs show larger band gaps, leading to blue-shifted emission, while larger QDs exhibit red-shifted emission. Proper capping agents or ligands prevent aggregation and stabilize the QDs, which is consistent with our observation of mono disperse particles.

## 11 Conclusion

Quantum dots have emerged as a versatile and transformative class of nanomaterials with remarkable optical, electronic, and chemical properties. Their size-tunable emission, high photostability, and broad absorption spectra make them suitable for a wide range of applications, including optoelectronics, photovoltaics, bioimaging, and sensing. Advances in synthesis techniques have allowed precise control over size, shape, composition, and surface functionalization, enabling tailored properties for specific applications. Despite these advantages, challenges such as toxicity, long-term stability, and scalable production remain critical hurdles for commercialization and biomedical use. Ongoing research focusing on environmentally friendly synthesis, surface passivation, and integration into functional devices is likely to address these limitations. Overall, quantum dots represent a promising frontier in nanotechnology, offering unprecedented opportunities to enhance performance across scientific and technological domains.

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