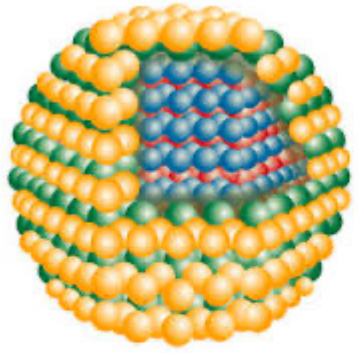
Quantum Dot (QD)



2023 Noble prize winner Prof. Bawendi and his II-VI QDs

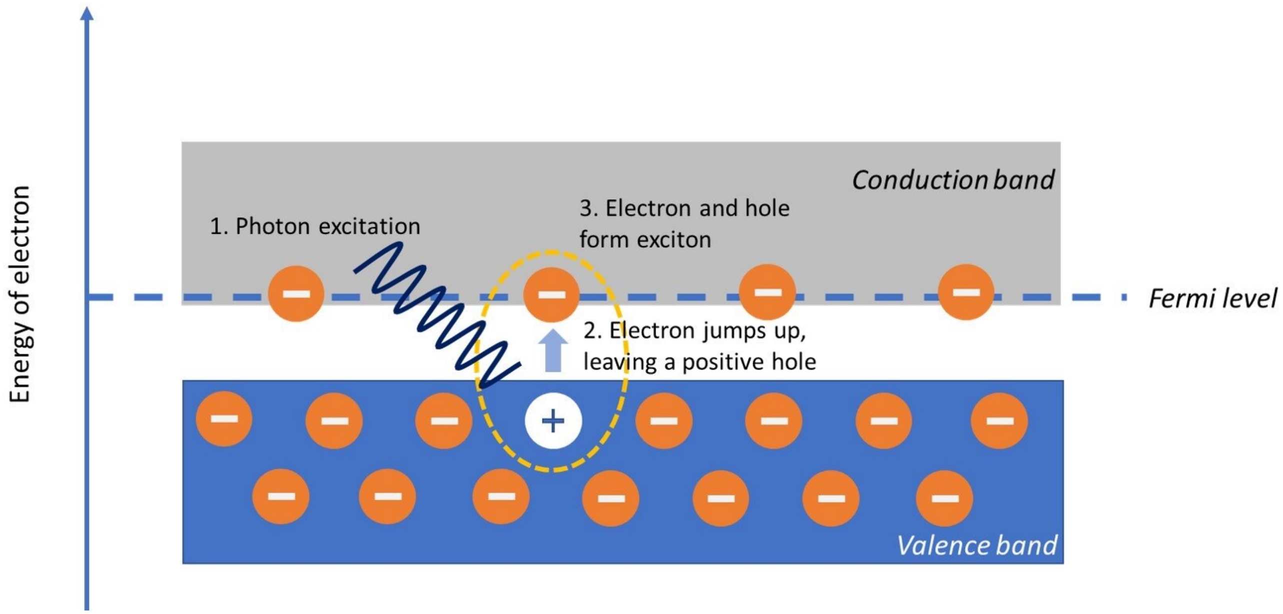
*Semiconductor nanocrystals tunable electro-optical properties

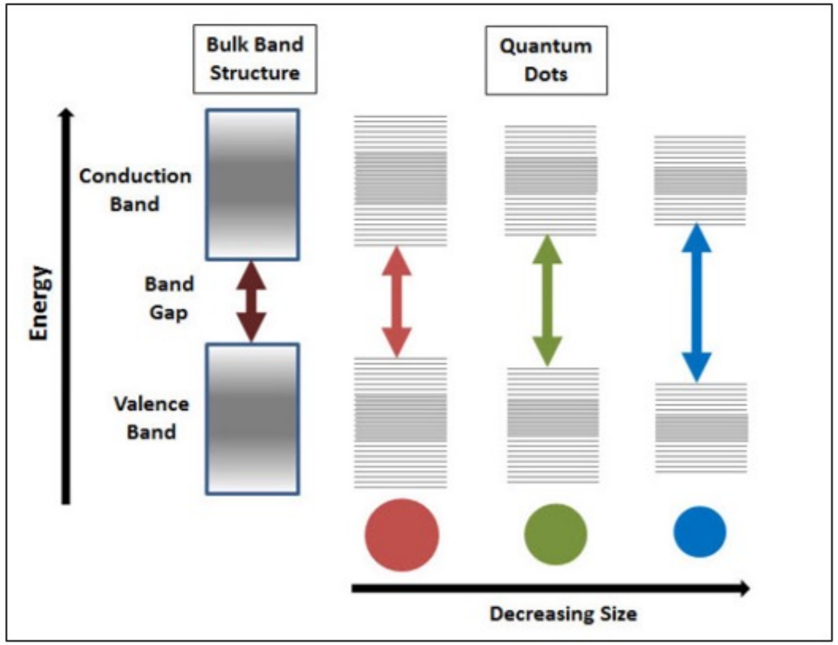
*Broad absorption, narrow emission UV-NIR

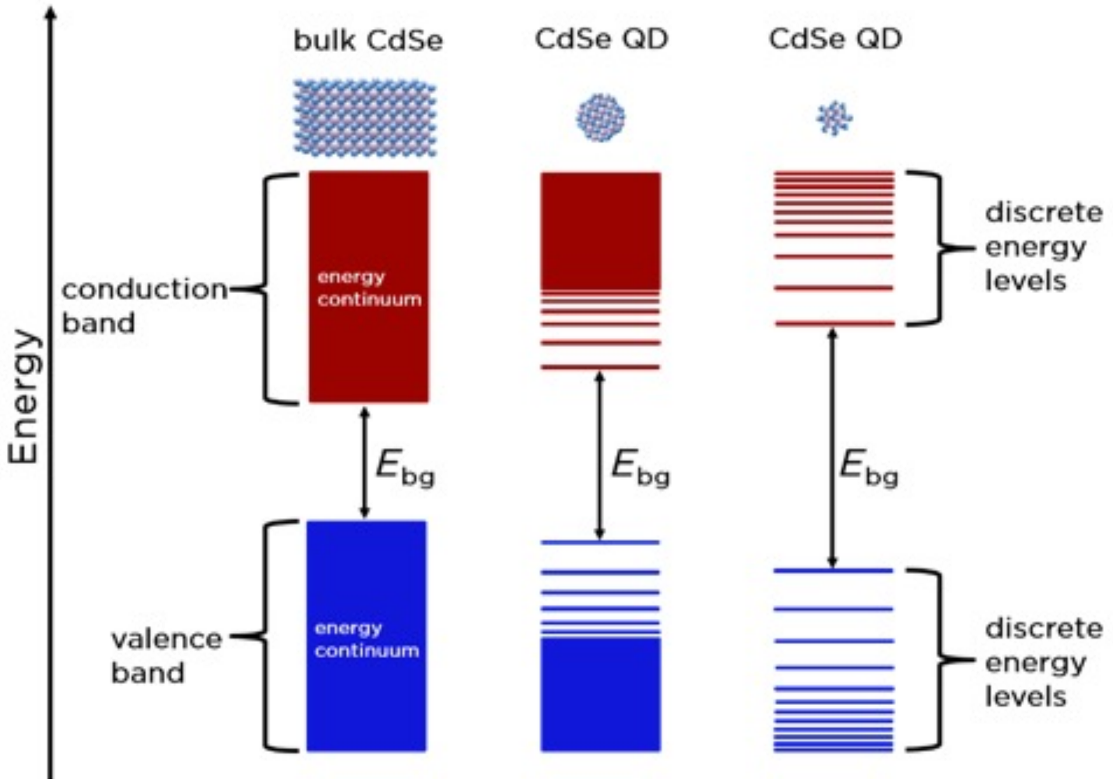
*Resistance to photobleaching

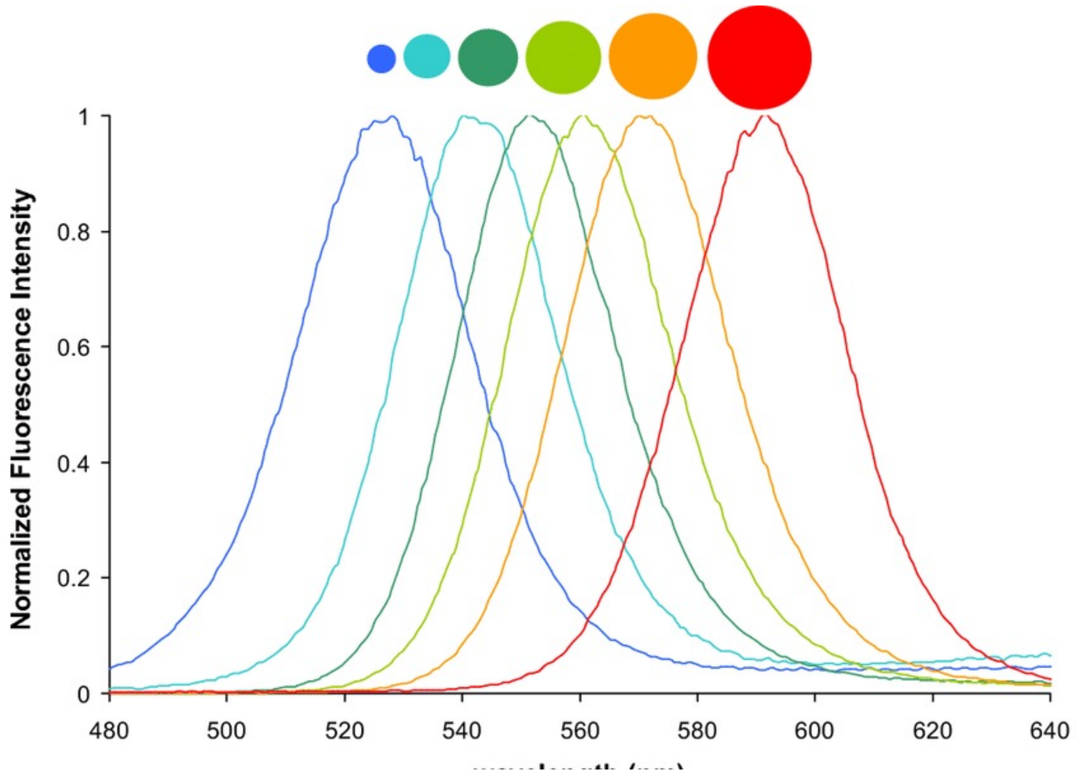
* Usually 2-10 nm diameter

*3D quantum confinement









Size tunable CdSe QDs' fluorescence spectra

Topics in Current Chemistry 378(2)
DOI:10.1007/s41061-020-0296-6

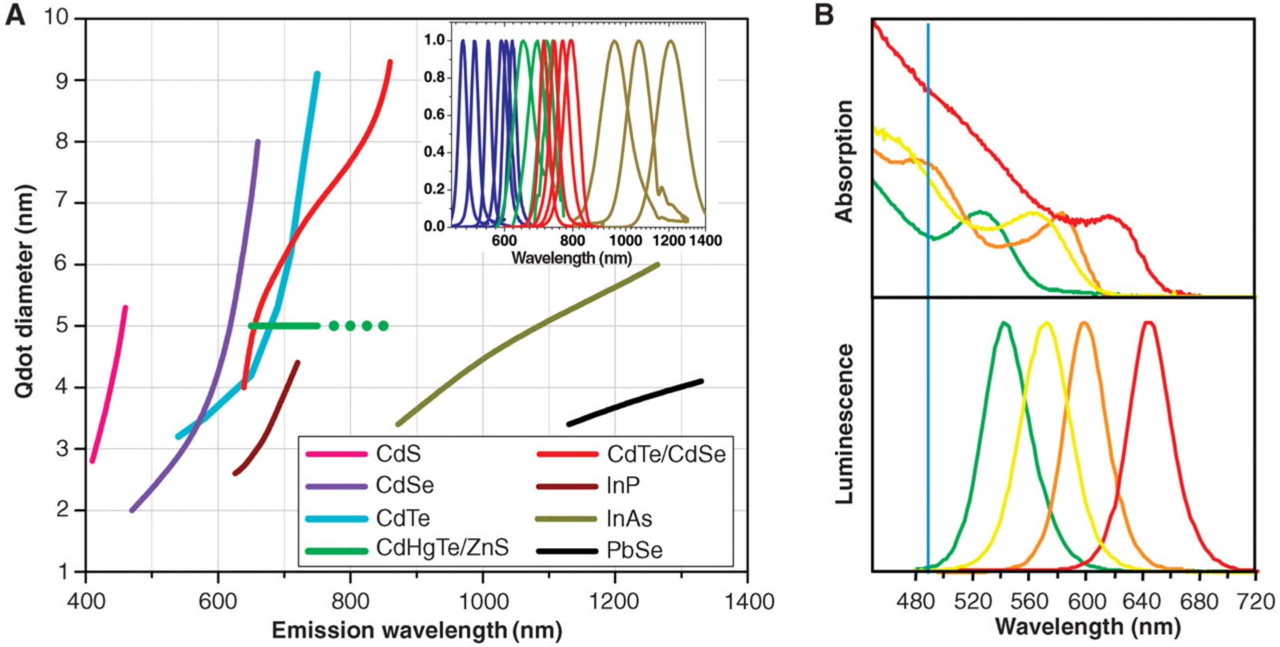
Periodic Table of the Elements

1 1IA 11A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.0079																	2 He Helium 4.00260
3 Li Lithium 6.941	4 Be Beryllium 9.01218											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.998403	10 Ne Neon 20.1797
11 Na Sodium 22.989768	12 Mg Magnesium 24.305											13 Al Aluminum 26.981539	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.95591	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.64	33 As Arsenic 74.92159	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium 98.9072	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90543	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.9665	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98037	84 Po Polonium [208.9824]	85 At Astatine 209.9871	86 Rn Radon 222.0176
87 Fr Francium 223.0197	88 Ra Radium 226.0254	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

Lanthanide Series	57 La Lanthanum 138.9055	58 Ce Cerium 140.115	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium 144.9127	62 Sm Samarium 150.36	63 Eu Europium 151.9655	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.0278	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium 237.0482	94 Pu Plutonium 244.0642	95 Am Americium 243.0614	96 Cm Curium 247.0703	97 Bk Berkelium 247.0703	98 Cf Californium 251.0796	99 Es Einsteinium [254]	100 Fm Fermium 257.0951	101 Md Mendelevium 258.1	102 No Nobelium 259.1009	103 Lr Lawrencium [262]

Alkali Metals	Alkaline Earths	Transition Metals	Basic Metals	Semi-Metals	Nonmetals	Halogens	Noble Gases	Lanthanides	Actinides

Types of QDs

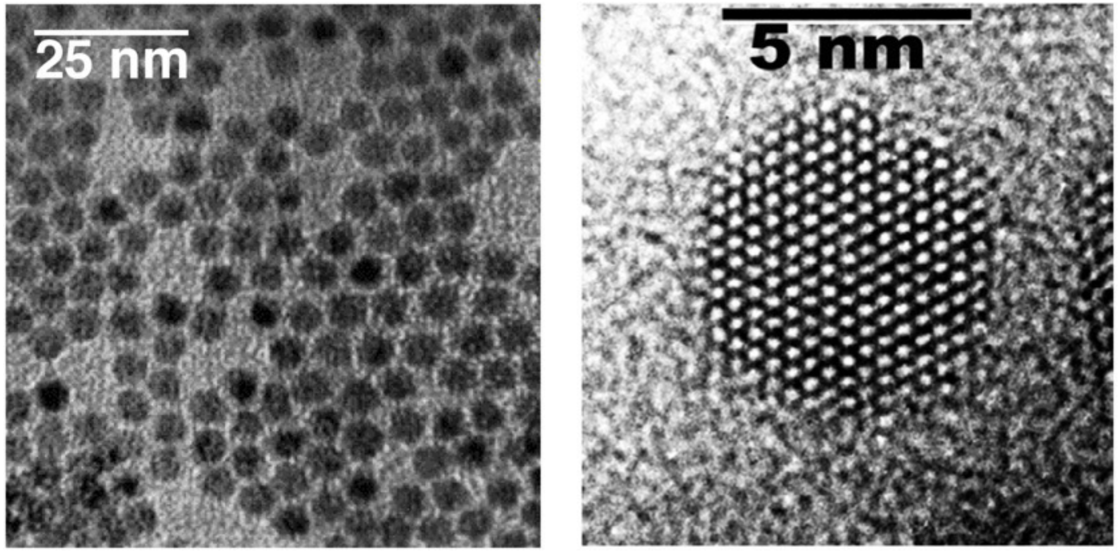


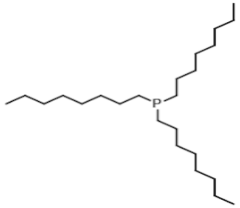
(A) Emission maxima and sizes of quantum dots of different composition. Quantum dots can be synthesized from various types of semiconductor materials (II-VI: CdS, CdSe, CdTe...; III-V: InP, InAs...; IV-VI: PbSe...) characterized by different bulk band gap energies.

(B) Absorption (upper curves) and emission (lower curves) spectra of four CdSe/ZnS qdot samples. The blue vertical line indicates the 488-nm line of an argon-ion laser.

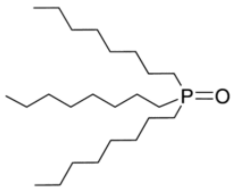
S. Weiss, *et al*. Quantum Dots for Live Cells, In Vivo Imaging, and Diagnostics, Science 307:538-44, 2005. DOI:10.1126/science.1104274

High-resolution TEM image of CdSe QDs





trioctyl phosphine (TOP)

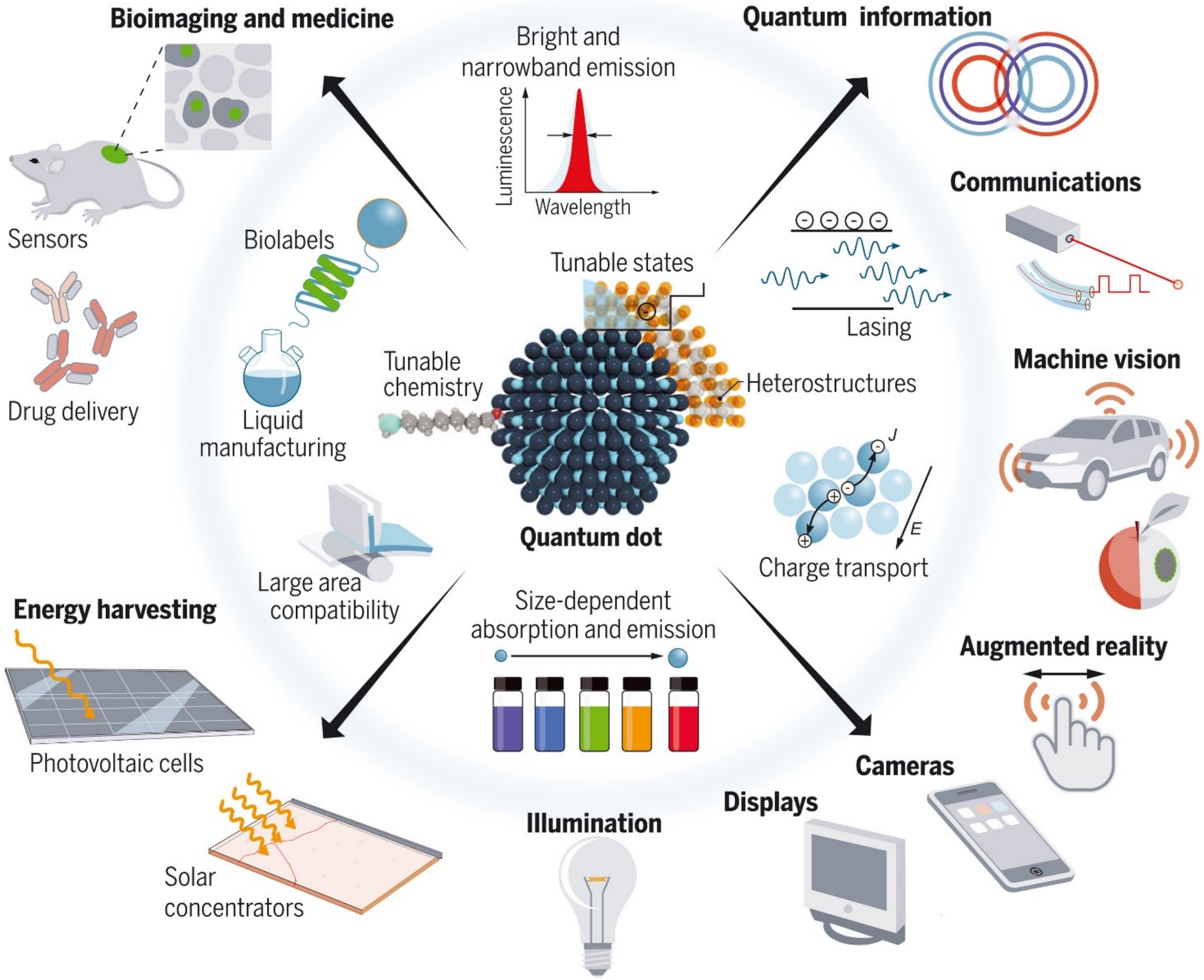


trioctyl phosphine oxide (TOPO)

http://www.qdots.com/live/upload_documents/xwusbsposter.pdf

QDs are also used in commercial applications, including:

- Photovoltaics
- Light-emitting diodes
- Lasers
- Single-photon sources
- Second-harmonic generation
- Quantum computing
- Cell biology research
- Biomedical Imaging
- Photodetectors
- Photodynamic therapy
- Microscopy
- Wastewater treatment



F. PELAYO GARCÍA DE ARQUER, et al, **Semiconductor quantum dots: Technological progress and future challenges,** ***SCIENCE*** 2021 Vol 373, DOI: 10.1126/science.aaz8541

Typical synthesis method for II-VI quantum dots

Hot injection synthesis: TOP/TOPO capped CdSe QDs early work by C. B. Murray, D. J. Norris, and M. G. Bawendi, *J. Am. Chem. Soc.* 1993, 115, 19, 8706, cited by 7773 publications

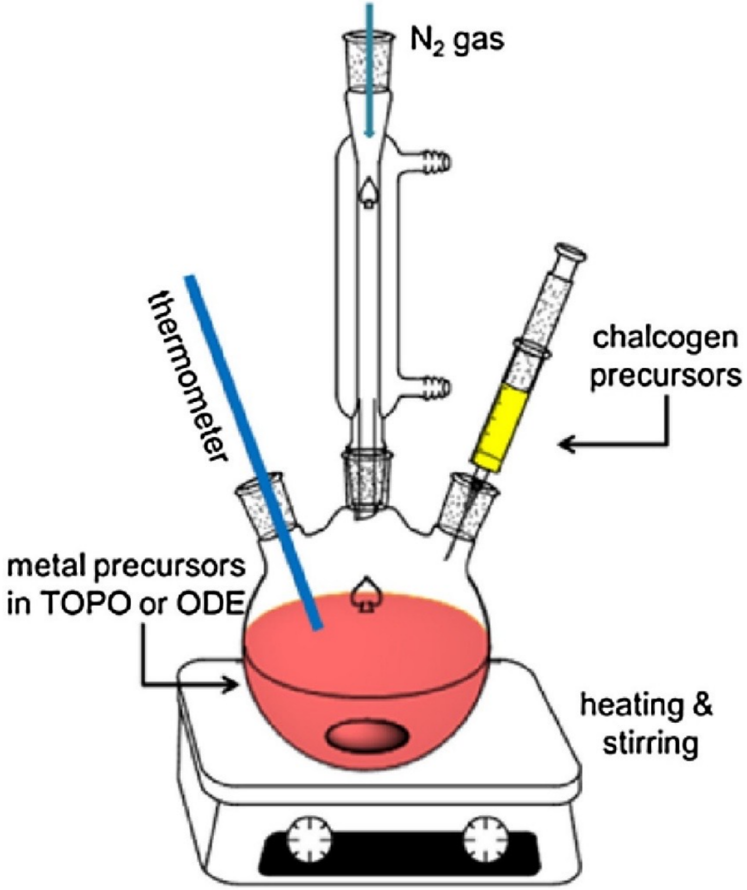
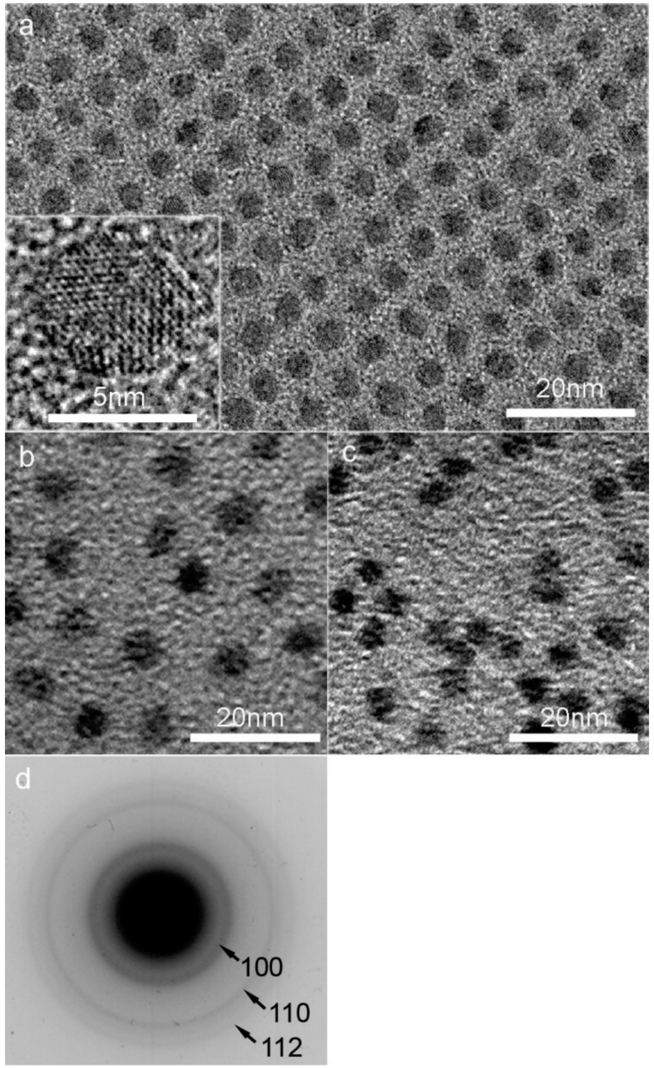
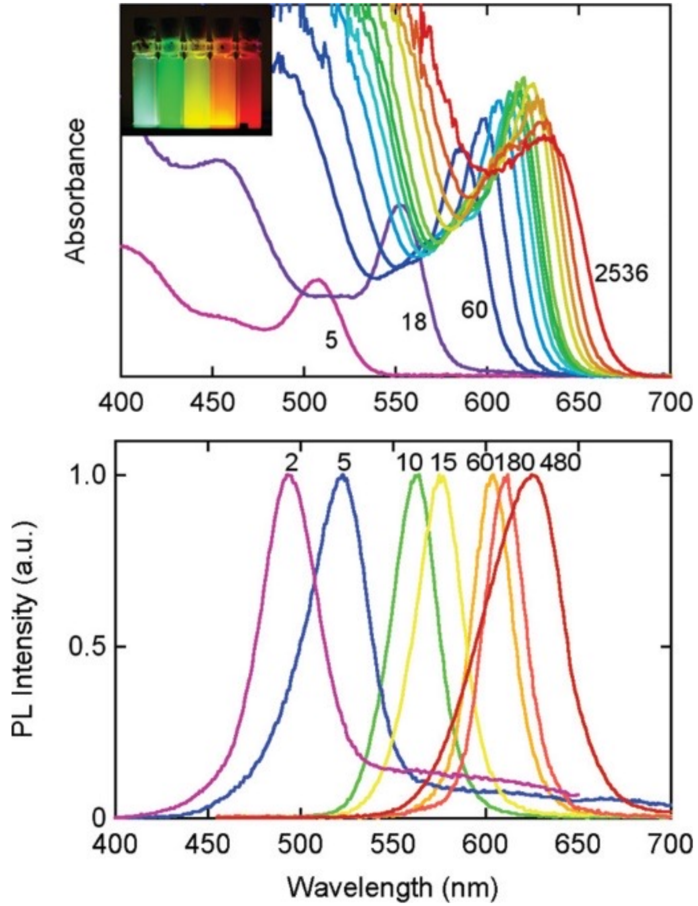


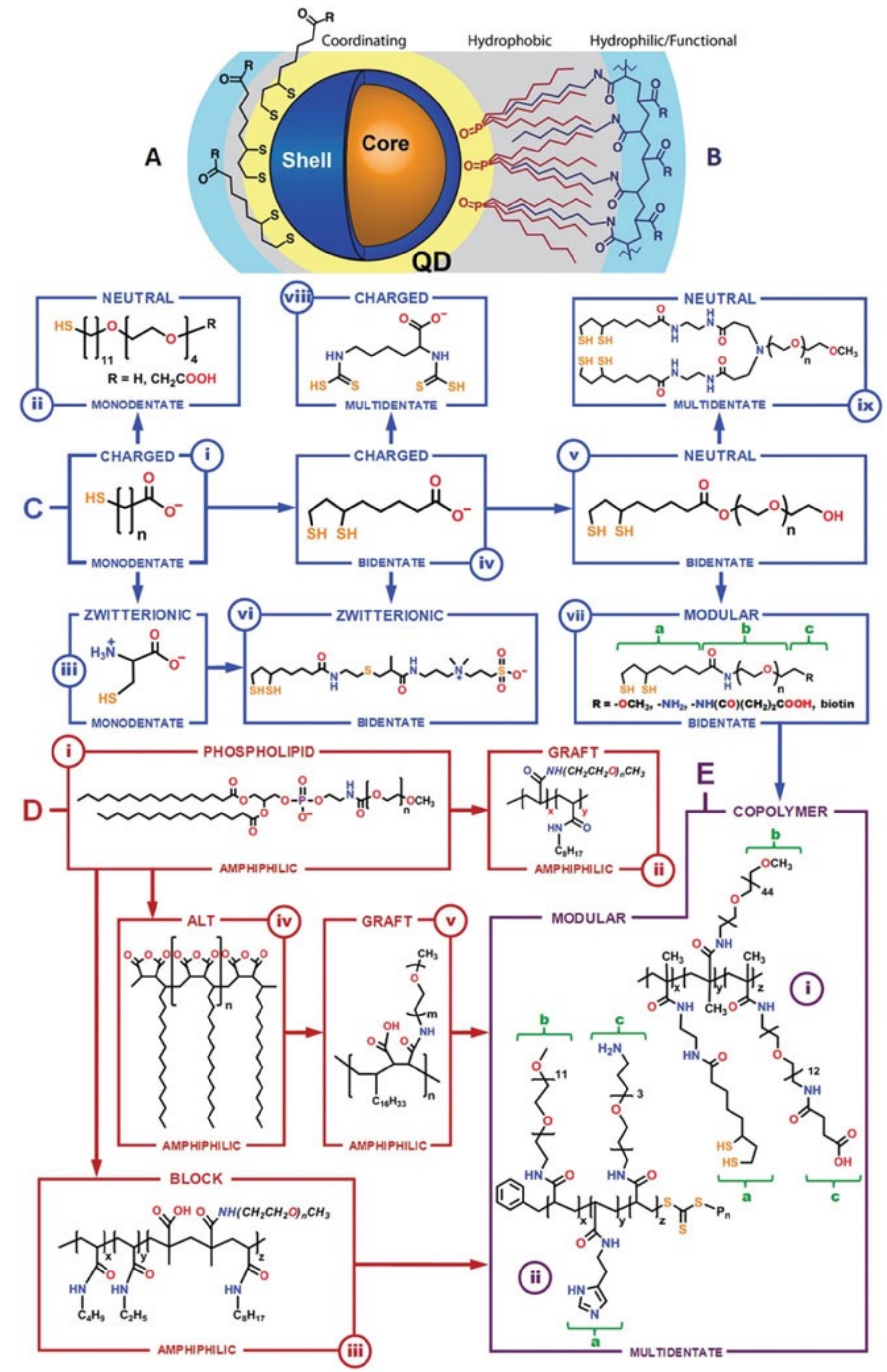
Figure after Y. Park, et al, JPPC, https://doi.org/10.1016/j.jphotochemrev.2017.01.002

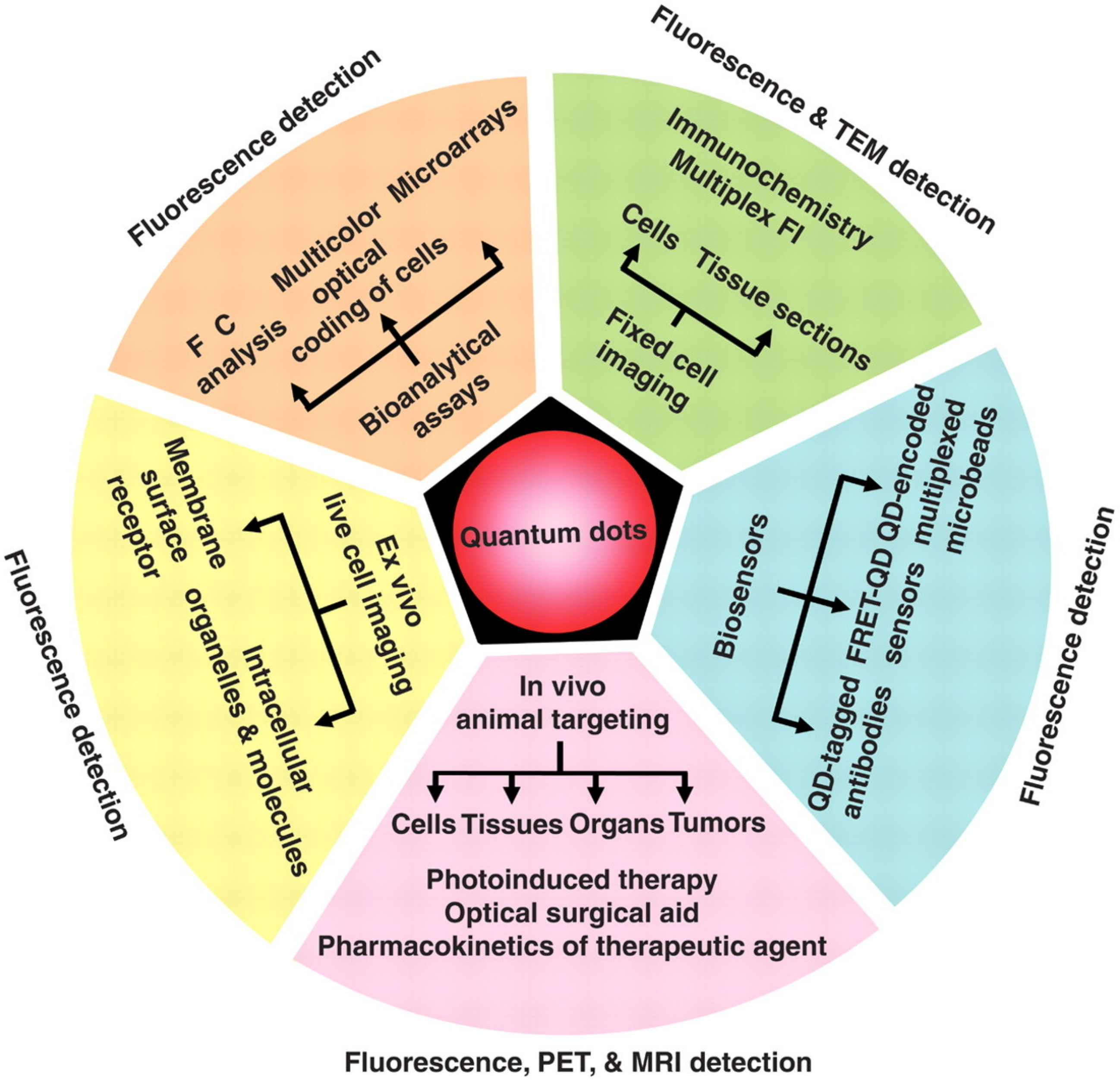




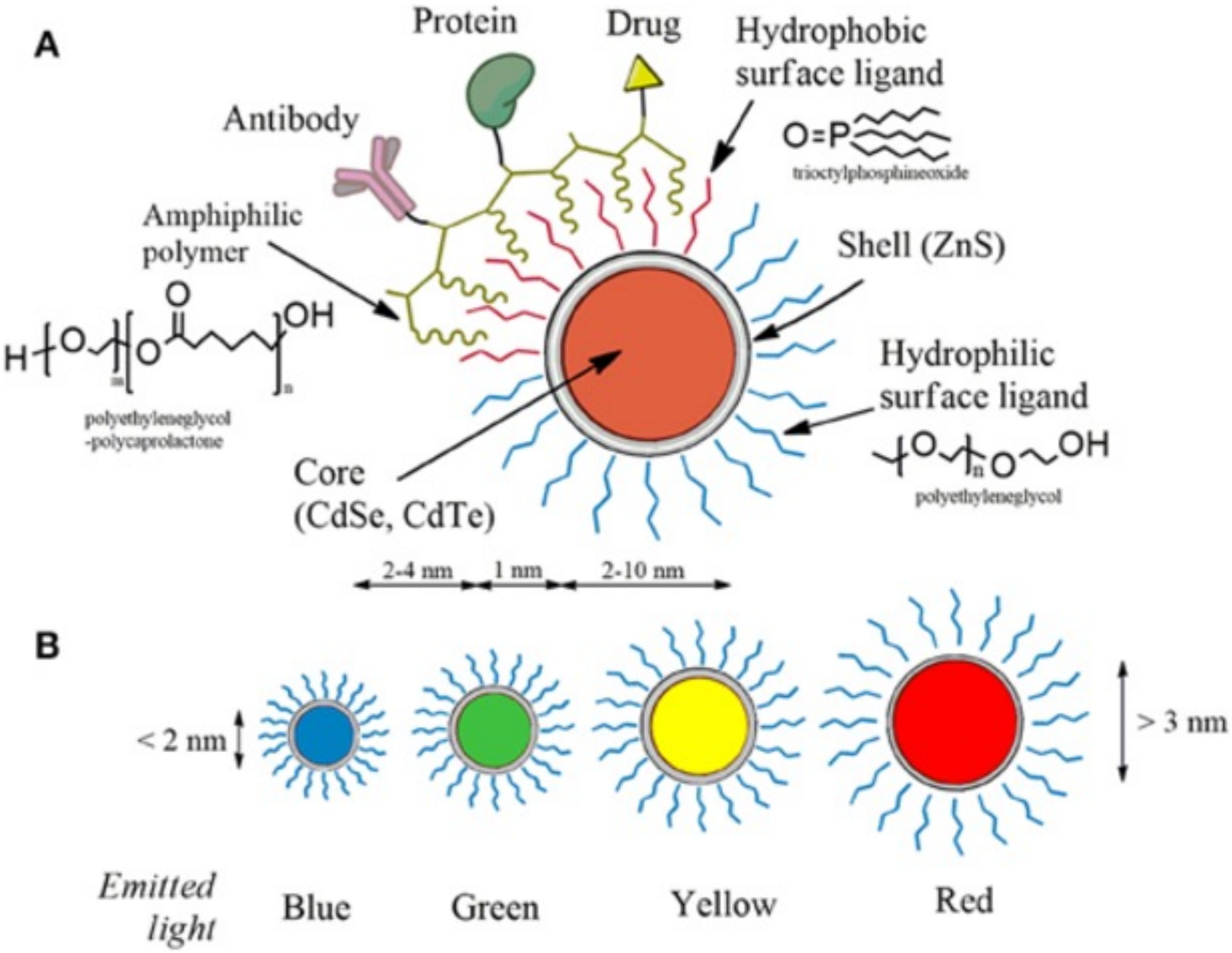
Light absorption and emission spectra of CdSe QDs, numbers are the reaction time (particle size increases with the reaction time)

After *J. Phys. Chem. C* **2008,** *112,* 17849–17854


A
B
C
D
E
QD
Core
Shell
Coordinating
Hydrophobic
Hydrophilic/Functional
NEUTRAL
MONODENTATE
R = H, CH2COOH
CHARGED
MULTIDENTATE
NEUTRAL
MULTIDENTATE
CHARGED
MONODENTATE
CHARGED
BIDENTATE
NEUTRAL
BIDENTATE
ZWITTERIONIC
MONODENTATE
ZWITTERIONIC
BIDENTATE
MODULAR
R = -OCH3, -NH2, -NH(CO)(CH2)2COOH, biotin
BIDENTATE
PHOSPHOLIPID
AMPHIPHILIC
GRAFT
AMPHIPHILIC
COPOLYMER
ALT
AMPHIPHILIC
GRAFT
AMPHIPHILIC
MODULAR
BLOCK
AMPHIPHILIC
MULTIDENTATE



S. Weiss, *et al*. Quantum Dots for Live Cells, In Vivo Imaging, and Diagnostics, Science 307:538-44, 2005. DOI:10.1126/science.1104274



Frontiers in Neuroscience 9(216):480

Synthesis of nearly monodisperse CdE (E = sulfur, selenium, tellurium) QDs

C. B. Murray, D. J. Norris, and M. G. Bawendi, *J. Am. Chem. Soc.* 1993, 115, 19, 8706–8715
cited by 7773 publications

All manipulationsinvolving alkylcadmium,silylchalconides,phosphines,and phosphine chalconides were carried out using standard airless procedures. Tri-n-octylphosphine[TOP] and bis(trimethylsilyl)sulfide[(TMS)2S]

Method1.The typical preparation of TOP/TOPO capped CdSe nanocrystallites follows: Fifty grams of TOPO is dried and degassed in the reaction vessel by heating to ~200°C at ~1Torr for ~20min, flushing periodically with argon. The temperature of the reaction flask is then stabilized at ~300 °C under ~1 atm of argon. Solution A is prepared by adding 1.00mL (13.35mmol) of Me2Cd to 25.0 mL of TOP in the drybox. Solution B is prepared by adding 10.0mL of the 1.0 M TOPSe stock solution (10.00mmol) to 15.0mL of TOP. Solutions A and B are combined and loaded into a 50-mL syringe in the drybox.

The heat is removed from the reaction vessel. The syringe containing the reagent mixture is quickly removed from the drybox and its contents delivered to the vigorously stirring reaction flask in a single injection through a rubber septum. The rapid introduction of the reagent mixture produces a deep yellow/orange solution with an absorption feature at 440-460 nm. This is also accompanied by a sudden decrease in temperature to —180°C. Heating is restored to the reaction flask and the temperature is gradually raised to 230-260°C.