Photonics: Fundamentals & Applications (Lect. 1, Monsoon 2021)

Instructor: Sayak Bhattacharya

Grading policy

- Assignments 15%
- Quiz 15%
- Mid-semester 20%
- Mini-project 25%
- Paper presentation 25%
- Relative grading.
- Penalty for late-submission of assignments: After the submission deadline is over, a penalty of 25% of the obtained marks 'll be imposed per day (so zero marks if submitted on 4th day after the deadline).
- Zero tolerance towards plagiarism and/or cheating in assignments/exams. Such cases 'll be dealt strictly.

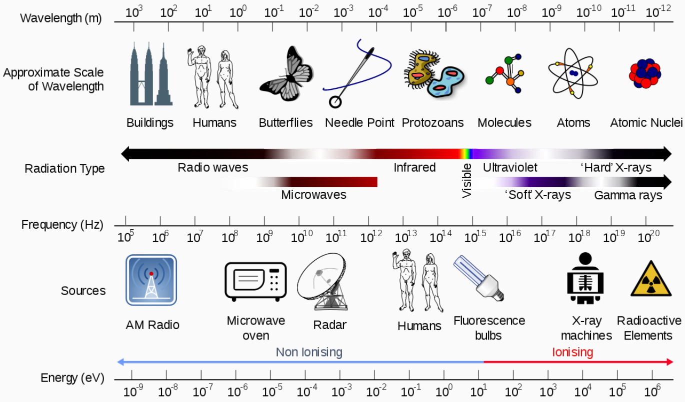
Course outline

- Review of Maxwell's equations.
- Module 1: Gauge transformation in Electromagnetics, Finite Difference Time Domain Method.
- Module 2: Lab: MIT Electromagnetic Equation Propagation (MEEP). Photonic band-gap (PBG) concept: Semiconductor of light, Lab: Introduction to MIT Photonic Bands (MPB). Hands-on design starts!
- Module 3: Lab: On-chip nanophotonic component design (optical waveguides, high Q resonators...)
- Module 4: Basics of Quantum Mechanics, Quantization of EM field: concept of photon.
- Module 5: Strong light matter interaction: Cavity QED, Applications to quantum computers and devices.

Reading

- David J. Griffiths, Introduction to Electrodynamics, Pearson 4th Ed. (2015).
- R. Feynman, R. Leighton, M. Sands, The Feynman Lectures on Physics
- B. Saleh and M. Teich, "Fundamentals of Photonics", Wiley, 3 ed. (2019)
- Stephen Barnett & Paul Radmore, "Methods in Theoretical Quantum optics", Oxford Series in Optical and Imaging Science (1997)
- J. J. Sakurai, "Modern Quantum Mechanics".
- Jelena Vuckovic, "Quantum Optics and Cavity QED with Quantum Dots in Photonic Crystals", Oxford Univ. press (2017) [free preprint available]
- John D. Joannopoulos et al., "Photonic crystals: Molding the flow of light" , Princeton Univ. Press, 2 ed. (2008) [free preprint available]

Electromagnetic spectrum (Image source: wiki)



Down memory lane: Corpuscular theory of light

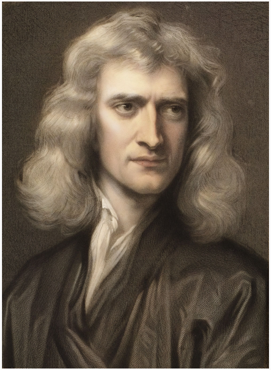


Figure 1: Isaac Newton ($1643 - 1727$)

Huygen's principle

Figure 2: Christiaan Huygens (1629 – 1695)

Double slit experiment

Figure 3: Thomas Young (1773 – 1829)

Unified theory of electricity and magnetism

- 1785 : Charles-Augustin de Coulomb reports inverse square law for charges
- 1800 : Alessandro Volta invents battery
- 1820 : Hans Christian Ørsted shows deflection of compass needle brought in the proximity of a current carrying wire
- 1820 : Ampere shows two parallel current-carrying wire attracts/repel depending on the direction of the current
- 1831 : Michael Faraday discovers electromagnetic induction

Unified theory of electricity and magnetism: Maxwell's equations

Figure 4: James Clerk Maxwell (1831 – 1879)

Unified theory of electricity and magnetism: Maxwell's equations

$$\left.\begin{aligned}
&\mathrm{PX} + (p+h)x + (k+l)y = \int \mathrm{A}\,dt - \int \mathrm{D}\,dt,\\
&\mathrm{Q(X-Z)} + (h+q)x + (m+n)y = \int \mathrm{D}\,dt - \int \mathrm{C}\,dt,\\
&\mathrm{RY} + (k+m)x + (r+o)y = \int \mathrm{A}\,dt - \int \mathrm{E}\,dt,\\
&\mathrm{S(Y+Z)} + (l+n)x + (o+s)y = \int \mathrm{E}\,dt - \int \mathrm{C}\,dt,\\
&\mathrm{GZ} = \int \mathrm{D}\,td - \int \mathrm{E}\,dt.
\end{aligned}\right\} \quad \ldots \quad (24)$$

Solving these equations for Z, we find

$$\left.\begin{aligned}
&\mathrm{Z}\left\{\frac{1}{\mathrm{P}}+\frac{1}{\mathrm{Q}}+\frac{1}{\mathrm{R}}+\frac{1}{\mathrm{S}}+\mathrm{B}\left(\frac{1}{\mathrm{P}}+\frac{1}{\mathrm{R}}\right)\left(\frac{1}{\mathrm{Q}}+\frac{1}{\mathrm{S}}\right)+\mathrm{G}\left(\frac{1}{\mathrm{P}}+\frac{1}{\mathrm{Q}}\right)\left(\frac{1}{\mathrm{R}}+\frac{1}{\mathrm{S}}\right)+\frac{\mathrm{BG}}{\mathrm{PQRS}}(\mathrm{P+Q+R+S})\right\}\\
&=-\mathrm{F}\frac{1}{\mathrm{PS}}\left\{\frac{p}{\mathrm{P}}-\frac{q}{\mathrm{Q}}-\frac{r}{\mathrm{R}}+\frac{s}{\mathrm{S}}+h\left(\frac{1}{\mathrm{P}}-\frac{1}{\mathrm{Q}}\right)+k\left(\frac{1}{\mathrm{R}}-\frac{1}{\mathrm{P}}\right)+l\left(\frac{1}{\mathrm{R}}+\frac{1}{\mathrm{Q}}\right)-m\left(\frac{1}{\mathrm{P}}+\frac{1}{\mathrm{S}}\right)\right.\\
&\left.+n\left(\frac{1}{\mathrm{Q}}-\frac{1}{\mathrm{S}}\right)+o\left(\frac{1}{\mathrm{S}}-\frac{1}{\mathrm{R}}\right)\right\}.
\end{aligned}\right\} \quad (25)$$

Figure 5: James Clerk Maxwell, A Dynamical Theory of the Electromagnetic Field, Royal Society Publishing (1865)

Oliver Heaviside: condensed form of Maxwell's equations (1885)

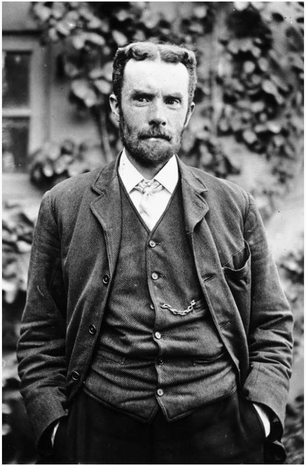


Figure 6: Oliver Heaviside (1850–1925)

Oliver Heaviside: condensed form of Maxwell's equations (1885)

- $\vec{\nabla}.\vec{E} = \frac{\rho}{\varepsilon_0}$
- $\vec{\nabla}.\vec{B} = 0$
- $\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
- $\vec{\nabla} \times \vec{B} = \mu_0 \left(\vec{J} + \frac{\partial \vec{D}}{\partial t} \right)$

Photoelectric effect: photon

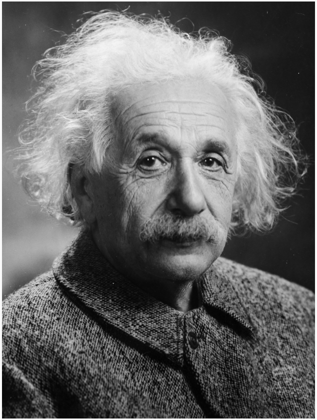
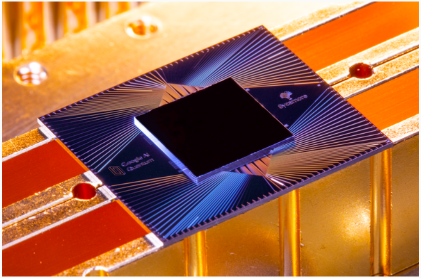


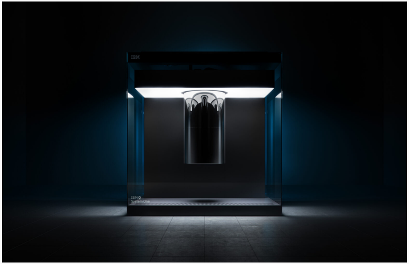
Figure 7: Albert Einstein (1879 – 1955)

Quantum optics

Figure 8: E.C. George Sudarshan (1931 – 2018)

The race for quantum supremacy: NextGen computers





Well...