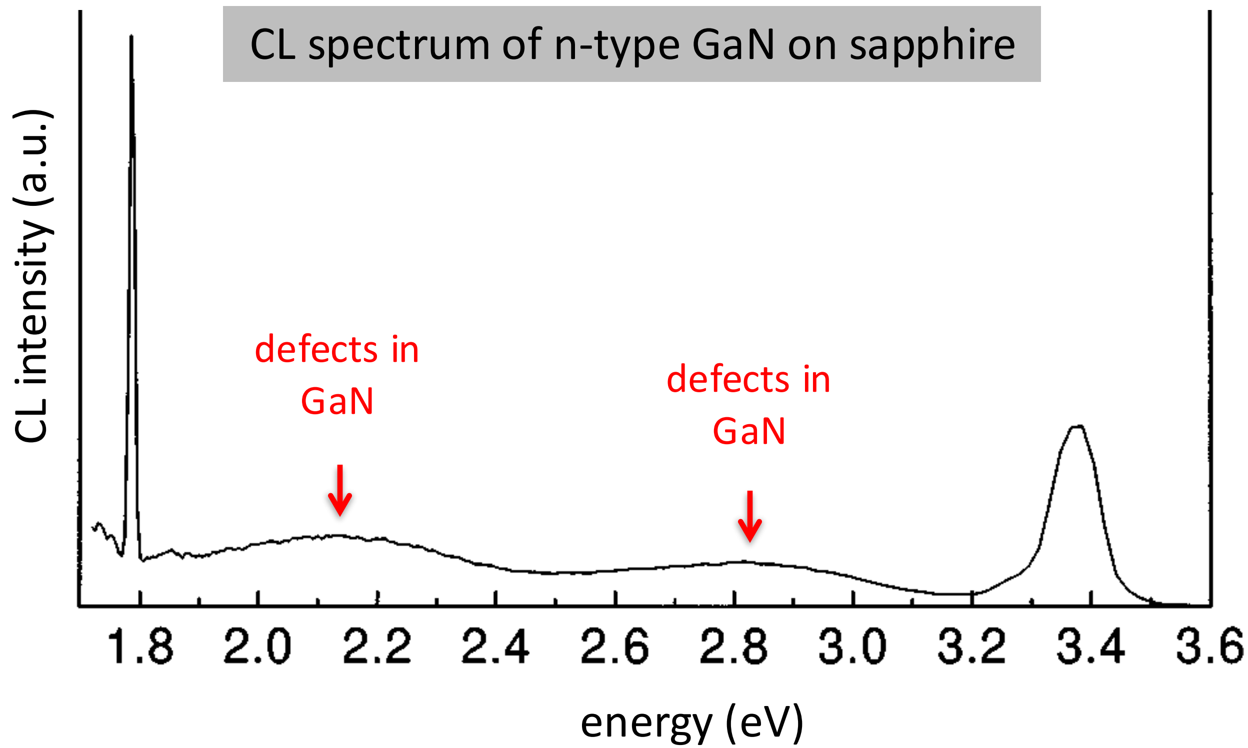
Class test 2: Sample questions

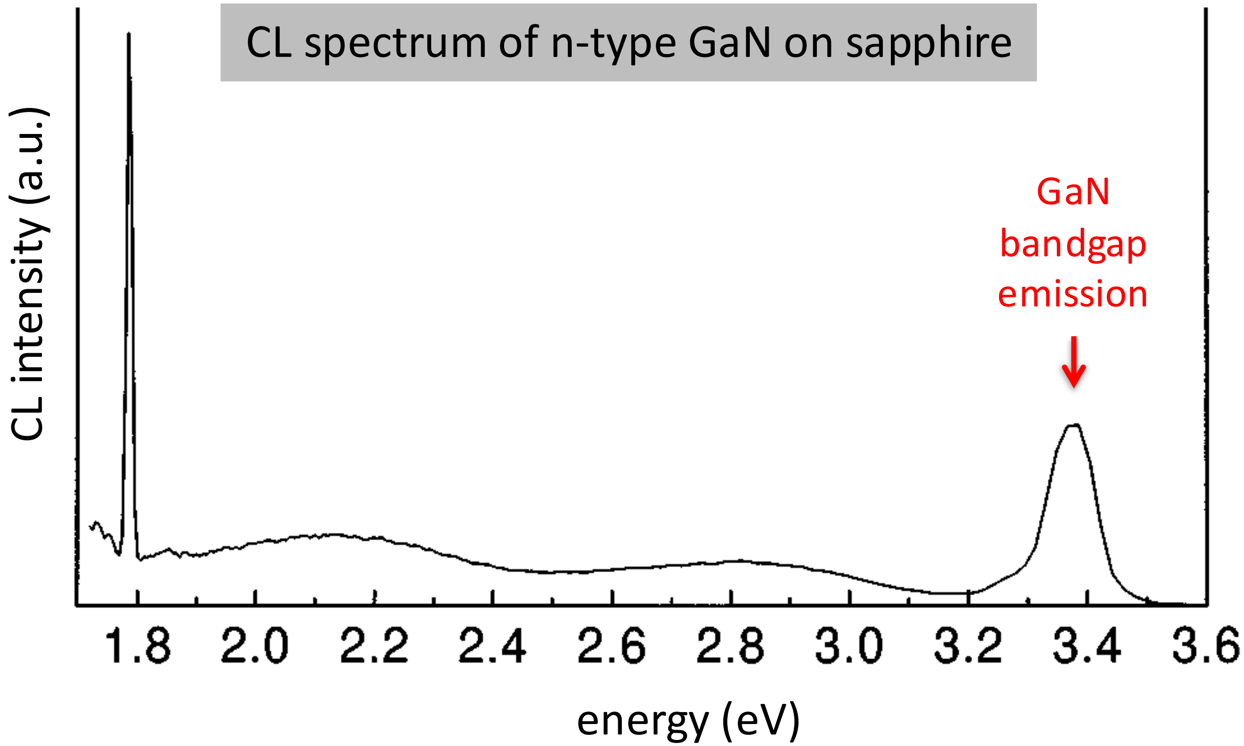
CL 1



Consider this cathodoluminescence (CL) spectrum from the semiconductor GaN. The GaN thickness is 2 microns and the electron beam energy is 30 keV. Which of the following limits the spatial resolution of CL images generated using the CL emissions indicated in red on the spectrum?

a) Electron beam energy.
~~b)~~ Energy of the CL photons.
~~c)~~ Absorption of light by GaN. → low energy emission does not limit the resolution
~~d)~~ Wavelength of the CL photons.
~~e)~~ Electron-hole pair recombination rate.
~~f)~~ Atomic weight of the $\boxed{\text{defects}}$ responsible for the CL emissions.
~~g)~~ Bandgap of GaN. ↳ if this was the lattice, the interaction is a function of atomic weight

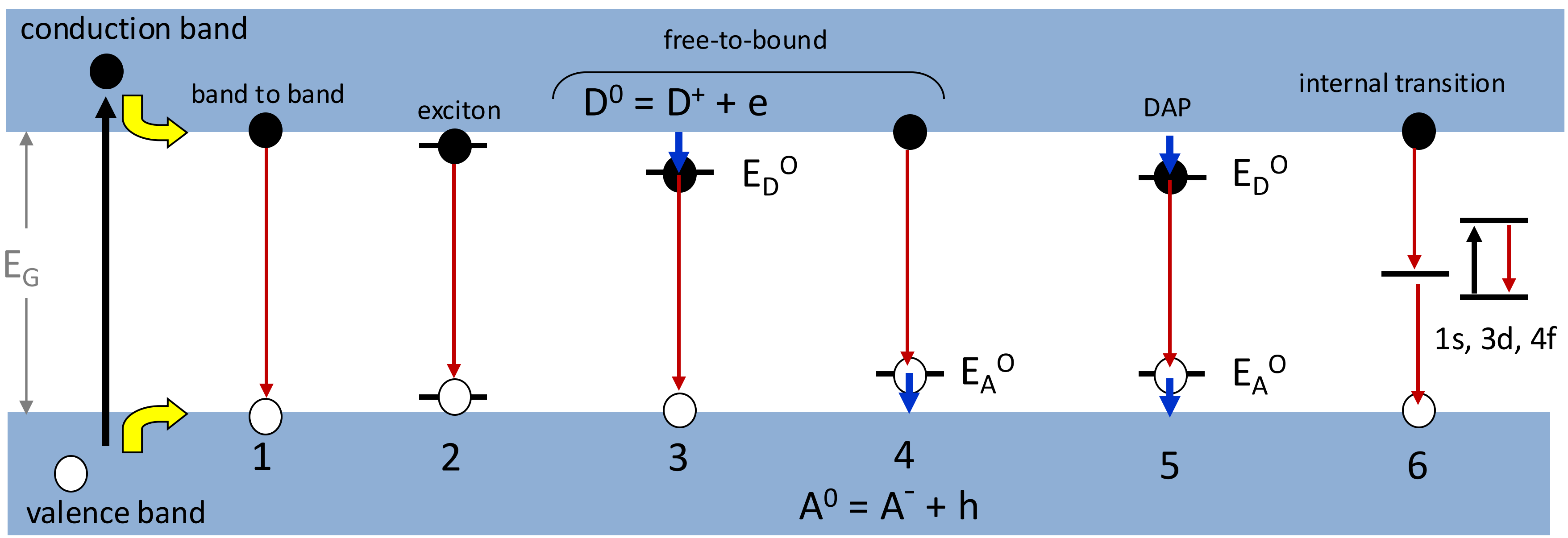
CL 2



Consider this cathodoluminescence (CL) spectrum from the semiconductor GaN. The GaN thickness is 2 microns and the electron beam energy is 30 keV. Which of the following limits the spatial resolution of CL images generated using the bandgap emission indicated in red on the spectrum?

a) Electron beam energy.
b) Energy of the CL photons.
c) Absorption of light by GaN. → absorbtion
d) Wavelength of the CL photons.
e) Electron-hole pair recombination rate.
f) Atomic weight of the defects responsible for the CL emissions.
g) Bandgap of GaN.

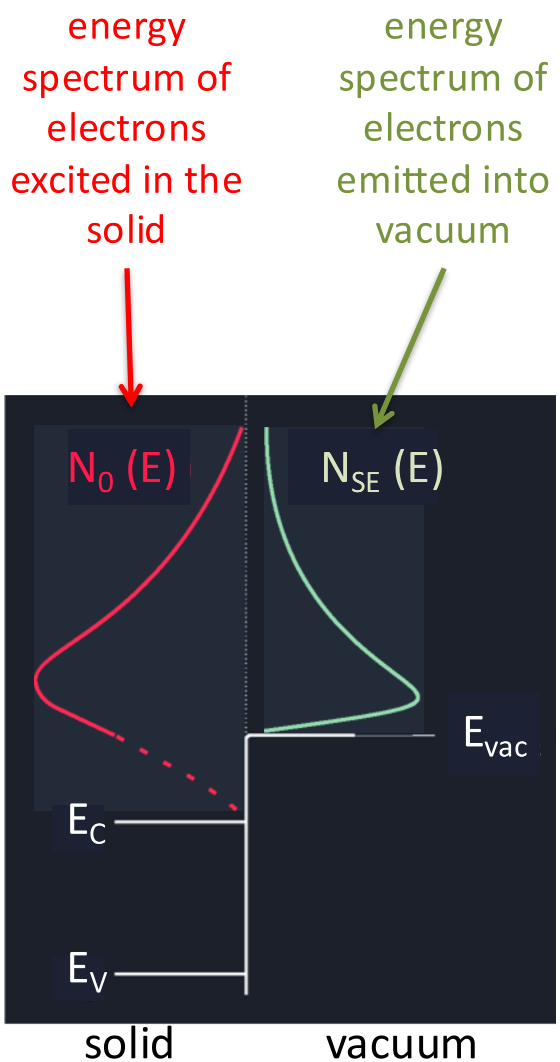
Cathodoluminescence



Consider this electron energy diagram showing various electron transitions in a sample measured using cathodoluminescence (CL) spectroscopy. Which statement is true?

~~a)~~ The black arrows indicate electron excitation (→ giving energy) pathways in a metal. → metal has no bandgap
~~b)~~ The red arrows indicate electron excitation pathways in a metal.
c) The red arrows indicate electron excitation pathways in a semiconductor.
~~d)~~ The red arrows indicate electron excitation pathways in a dielectric.
c & d are esentially the same
e) The black arrows indicate photon absorption pathways in a dielectric.
~~f)~~ The black arrows indicate photon absorption pathways in a metal.

Sample class test question



Consider this electron energy diagram of the sample-vacuum interface. Superimposed on the diagram are plots of the energy spectra of secondary electrons excited in the sample by an electron beam, and secondary electrons emitted from the sample and used to form an image.

Why are the two energy spectra not identical?

nonsense ←

~~a)~~ Because emitted secondary electrons are accelerated towards a detector.

b) Because of electron-hole pair recombination in the sample.

electron needs to be at E_c

c) Because of electron diffusion in the sample.

~~d)~~ Because the electron image is out of focus.

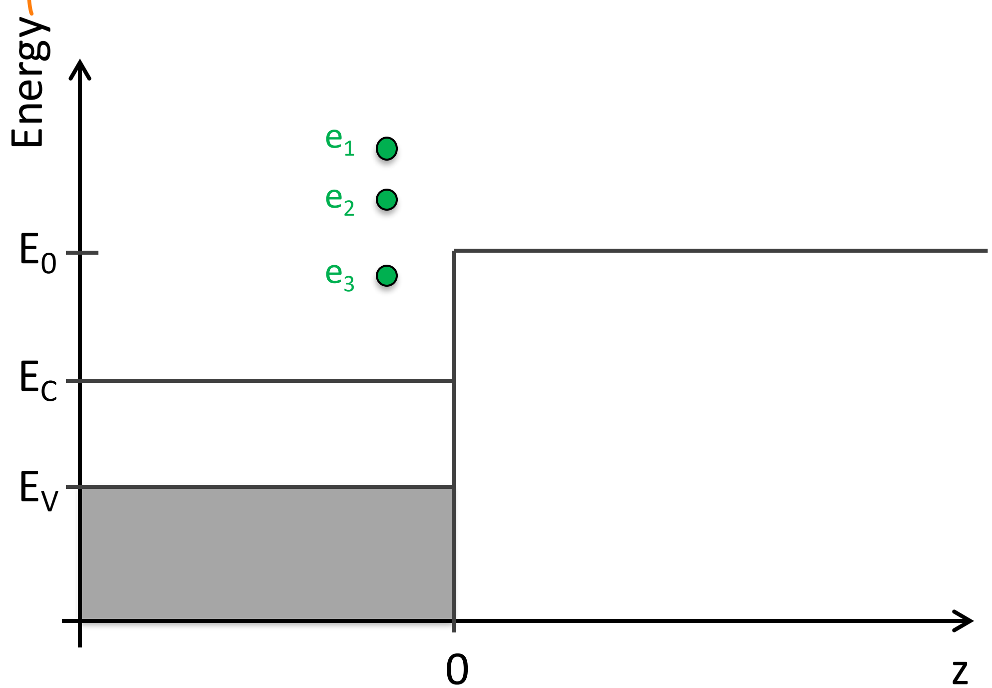
~~e)~~ Because the electron beam energy is smaller than the bandgap energy.

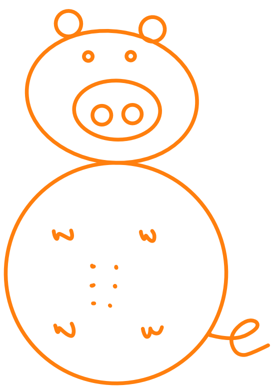
→ thermalises; are loosing energy and are reflected into the sample (inelastic)

Secondary electron emission

$E_T = \frac{1}{2}mv^2$

total energy





Consider this electron energy diagram of a sample imaged using a scanning electron microscope. The circles labelled e_1, e_2 and e_3 represent electrons excited in the sample by the electron beam. Your lecturer makes the claim that “electron e_1 is guaranteed to be emitted from the sample with a probability of 100%”. This statement is TRUE or FALSE because:

a) FALSE because the electron energy is too low.
b) FALSE because the electron energy is too high.

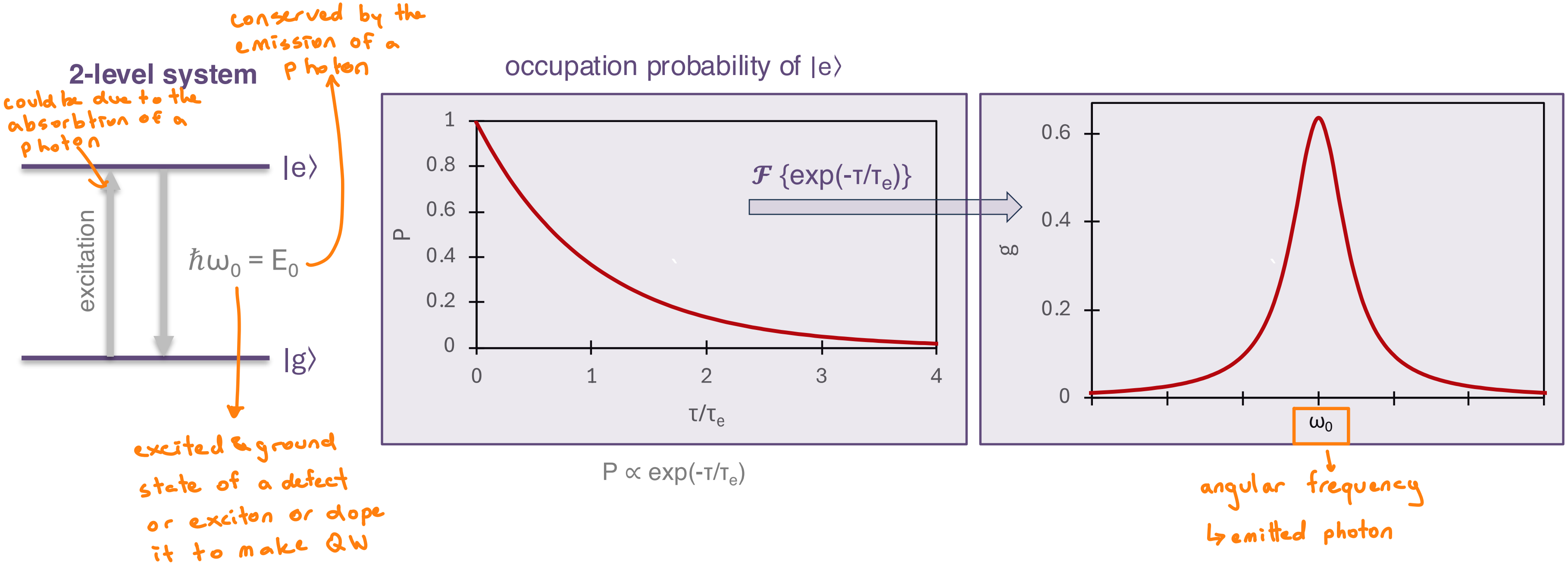
this is relative as the energy is already above the threshold

c) TRUE because the electron energy is greater than the vacuum level.
d) TRUE because the electron energy is greater than the work function of the sample.
e) TRUE because energy must be conserved when the electron crosses the solid-vacuum interface.
f) TRUE because because momentum must be conserved when the electron crosses the solid-vacuum interface.

& energy conservation

g) FALSE because because momentum must be conserved when the electron crosses the solid-vacuum interface.

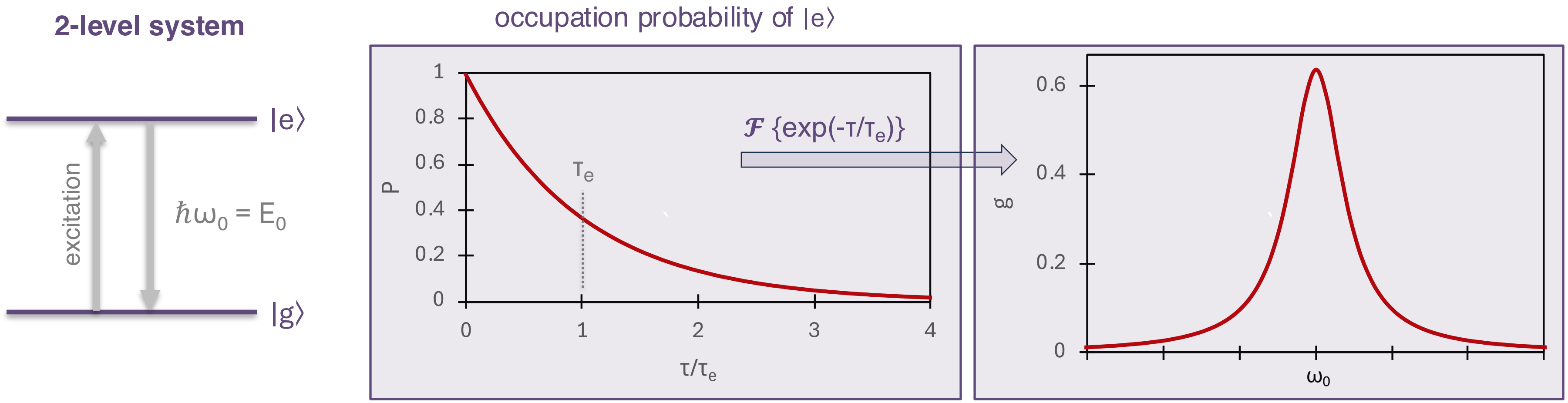
Photon emission



Consider this representation of a 2-level system, and 2 associated curves P(τ) and g(ω). What is the physical meaning of ω_0?

~~a)~~ The angular frequency of the electron excited from state |g⟩ to state |e⟩.
~~b)~~ The lifetime of the electron excited from |g⟩ to |e⟩.
~~c)~~ The rate at which the electron residing in |g⟩ is excited into |e⟩
d) The angular frequency of the photon emitted from the 2-level system.
~~e)~~ The uncertainty in the frequency of the photon emitted from the 2-level system.

Photon emission



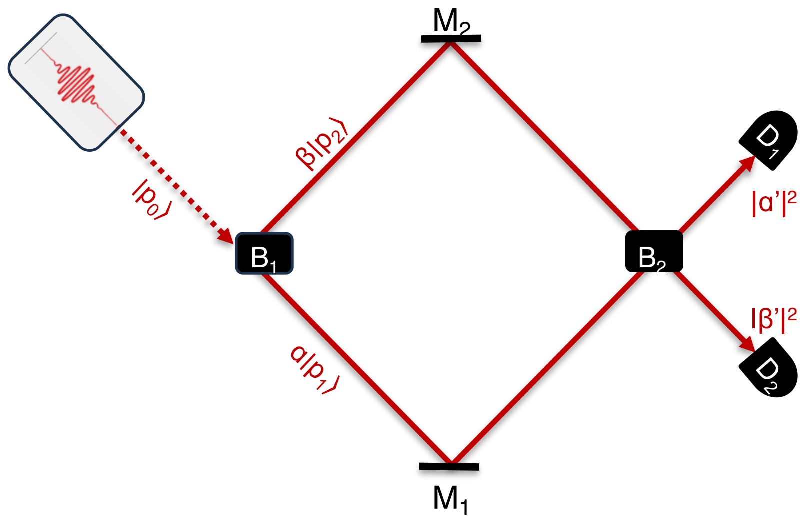
$P \propto \exp(-\tau/\tau_e)$

Probabilistic

Consider this representation of a 2-level system, and 2 associated curves P(τ) and g(ω). What is the physical meaning of τ_e?

a) The lifetime of the photon emitted from the 2-level system.
b) The lifetime of the electron in the ground state |g⟩.
c) The lifetime of the electron in the excited state |e⟩.
d) The rate at which the electron residing in |g⟩ is excited into |e⟩
e) The uncertainty in the frequency of the photon emitted from the 2-level system.

Photon interference



Consider this single photon interference setup. M, B and D represent mirrors, 50%-50% beamsplitters and detectors. p_1 and p_2 represent 2 possible photon paths in the setup. Which statement is true?

if B_2 was not there, (b) would be correct

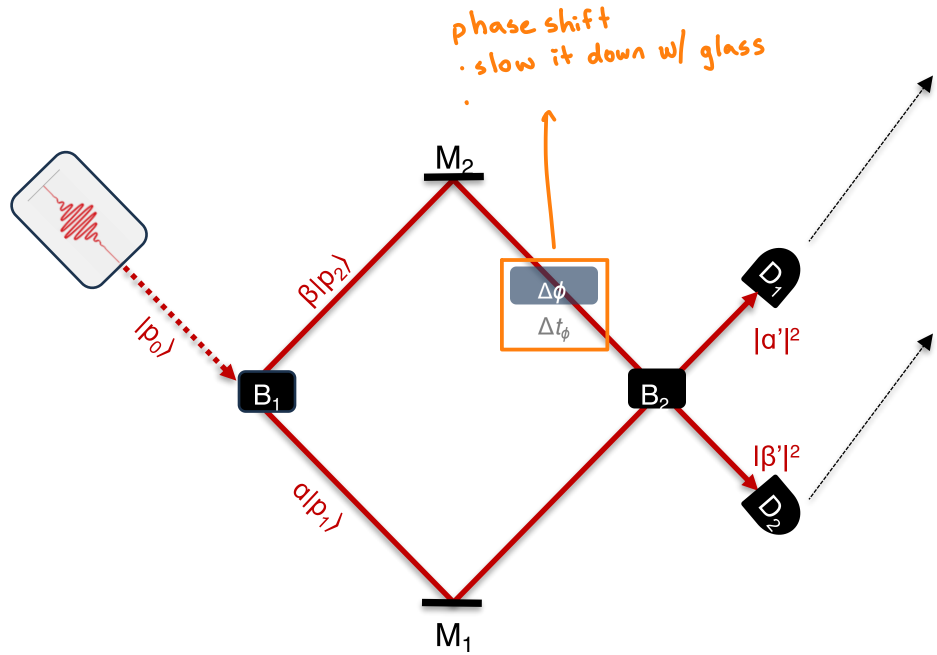
~~a)~~ Each photon injected into the setup splits into 2 photons at B1. The 2 photons subsequently recombine and form a single photon at B_2. implies there is a phase shift

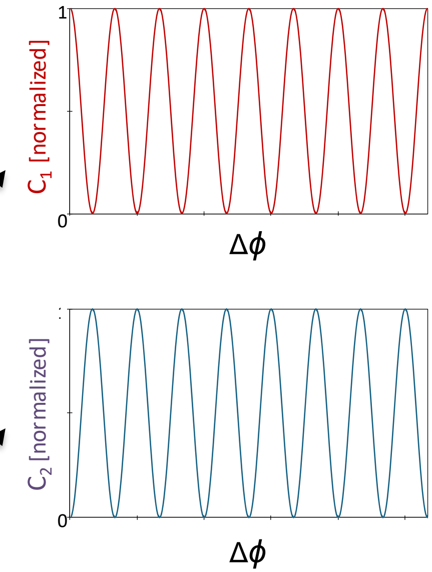
~~b)~~ Each photon injected into the setup has a 50% chance of travelling to detector D_1 along path 1 and 50% chance of travelling to detector D_2 along path 2. → doesn't assume the superposition state: not 50/50 → will be 100%

~~c)~~ The wave function of each photon injected into the setup splits into 2 components at B1, which explore paths 1 and 2 in parallel in a superposition state which collapses into a definite state at B_2.

d) The wave function of each photon injected into the setup splits into 2 components at B1, which explore paths 1 and 2 in parallel in a superposition state which collapses into a definite state at one of the detectors.

Photon interference





Consider this single photon interference setup. M, B and D represent mirrors, 50%-50% beamsplitters and detectors. C_1 and C_2 are photon detection rates at detectors 1 and 2, measured versus the phase shift $\Delta\phi$. Which statement is true?

↦ interference occurs at B_2

~~a)~~ C_1 and C_2 are interference patterns generated because each photon injected into the setup self-interferes at D_1 and D_2.

~~b)~~ C_1 and C_2 are interference patterns generated because each photon injected into the setup self-interferes at B_1.

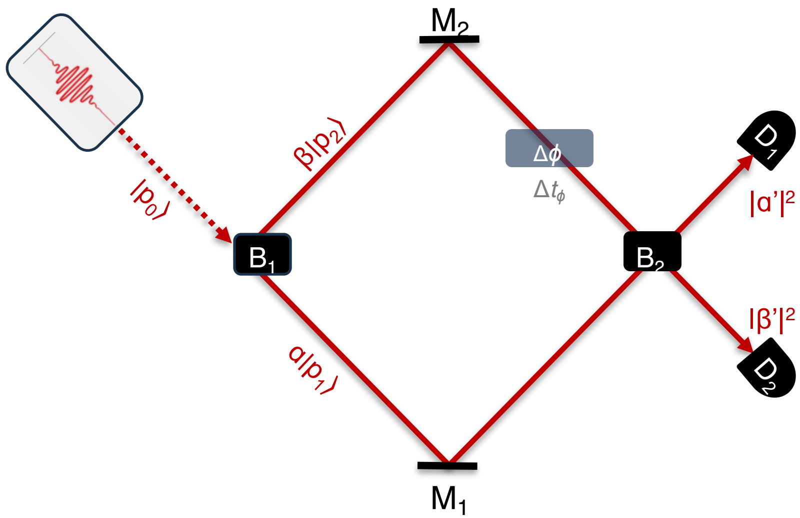
c) C_1 and C_2 are interference patterns generated because each photon injected into the setup self-interferes at B_2.

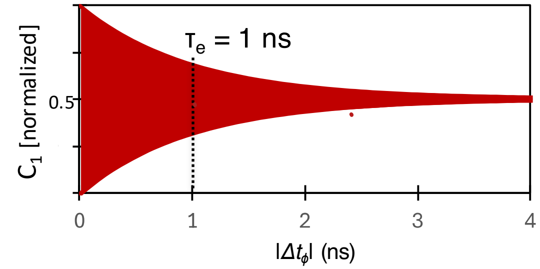
~~d)~~ C_1 and C_2 are interference patterns generated because consecutive photons injected into the setup interfere at B_1.

~~e)~~ C_1 and C_2 are interference patterns generated because consecutive photons injected into the setup interfere at B_2.

↳ could be true if the phaseshift is big enough

Photon interference





Consider this single photon interference setup. M, B and D represent mirrors, 50%-50% beamsplitters and detectors. C_1 is the photon detection rate at detector 1 measured versus the phase shift $\Delta\phi$. Photons injected into the setup are generated by a 2-level system. What is the quantity τ_e?

a) Lifetime of the photon travelling from B_1 to D_1.
b) Lifetime of the photon travelling from B_1 to B_2.
c) Lifetime of the photon travelling from B_2 to D_1.
d) Excited state lifetime of the 2-level system.
e) Ground state lifetime of the 2-level system.