

**Question:** *Where's the optics in quantum optics?*

(i) Optics is about the propagation of light. When we learn about optics, we think of telescopes and cameras and lenses. In the optics, we lenses, mirrors, beam splitters, diffraction, absorption, etc. Yet when we quantized Maxwell's equations, there didn't seem to be any of these devices in sight.

*Where do the optical elements enter into Maxwell's equations?* E.g. how does a beam splitter go into Maxwell's equations?

(ii) Given a beam splitter, the electric fields on the input ports and output ports are related by

$$\begin{pmatrix} E_1^{\text{out}} \\ E_2^{\text{out}} \end{pmatrix} = \begin{pmatrix} R & T \\ T & R \end{pmatrix} \begin{pmatrix} E_1^{\text{in}} \\ E_2^{\text{in}} \end{pmatrix}$$

with  $T$  and  $R$  real. (Four complex phases are also possible, one for each element of the matrix on the right hand side, but we ignore these.)

*Can you guess (not derive!) the relation between the input and output field operators  $a_j^{\text{in}}$  and  $a_j^{\text{out}}$  are?* Hint, think of the equation relating the electric field to the quantum field operator.