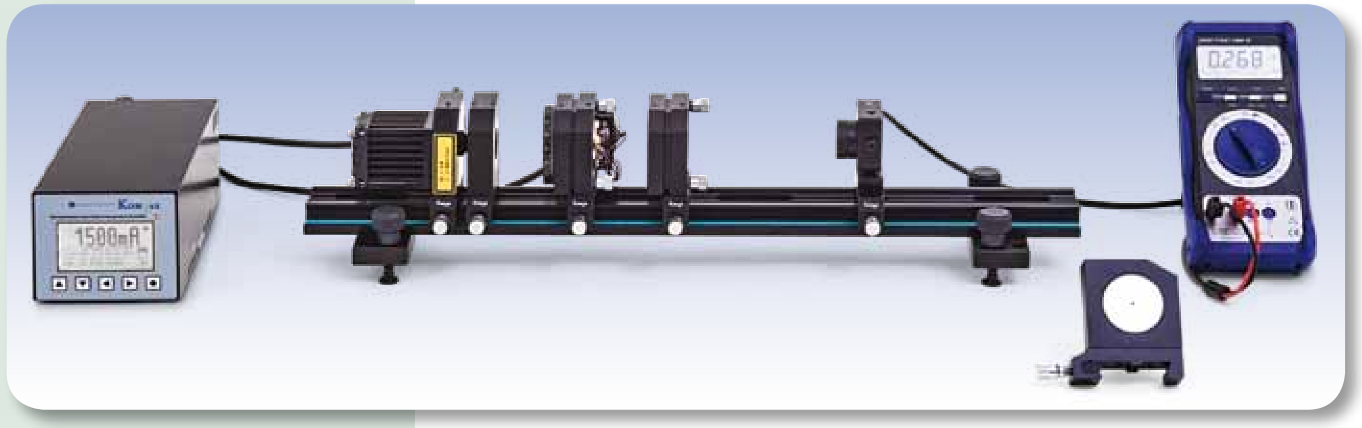
ND:YAG-LASER



EXPERIMENT PROCEDURE

- **Generate radiation at double the original frequency by adding a KTP crystal to the resonator.**
- **Measure the output power of the radiation at the doubled frequency as a function of the power associated with the fundamental wave.**
- **Study how the generated radiation depends on the alignment of the crystal and the temperature.**

OBJECTIVE

Frequency doubling inside the resonator of a Nd:YAG laser

SUMMARY

Materials often change their optical properties in strong electromagnetic fields. For instance, it is possible for the frequency of high-intensity laser light passing through such materials to be doubled. In this experiment, a KTP (potassium titanyl phosphate) crystal is used to generate green light with a wavelength of 532 nm from the 1064-nm infra-red radiation output by an Nd-YAG laser by means of frequency doubling. The crystal is suitable in a number of respects, such as its strongly non-linear optical characteristics, and its low absorption of radiation at the original frequency and double the frequency.

REQUIRED APPARATUS

Quantity	Description	Number
1	Laser Diode Driver and Two-Way Temperature Controller Dsc01-2.5	**1008632**
1	Optical Bench KL	**1008642**
1	Diode Laser 1000 mW	**1009497**
1	Nd:YAG Cristal	**1008635**
1	Frequency Doubling Module	**1008636**
1	Laser Mirror II	**1008639**
1	PIN Photodiode	**1008640**
1	Filter BG40	**1017874**
1	Alignment Laser Diode	**1008634**
1	Transport Case KL	**1008651**
1	Laser Safety Goggles for Nd:YAG Laser	**1002866**
1	Digital Multimeter P3340	**1002785**
1	HF Patch Cord, BNC/4 mm Plug	**1002748**
1	IR Detector Card	**1017879**

WARNING

This experiment involves operation of class-4 laser equipment which emits light in the (invisible) infra-red part of the spectrum. Goggles which protect against laser light should always be worn. Even when wearing such goggles, never look at the laser beam directly.

GENERAL PRINCIPLES

Materials often change their optical properties in strong electromagnetic fields. For instance, it is possible for the frequency of high-intensity laser light passing through such materials to be doubled. To describe such phenomena it is necessary to consider the polarisation, which changes in a way which is not linearly proportional to electric field strength:

If the material is non-magnetic, the wave equation for the electric field strength E has the following form:

$$\Delta\boldsymbol{E}(\boldsymbol{r},t)-\frac{1}{c^2}\cdot\frac{\partial^2}{\partial t^2}\boldsymbol{E}(\boldsymbol{r},t)=\frac{1}{\varepsilon_0\cdot c^2}\cdot\frac{\partial^2}{\partial t^2}\tilde{\boldsymbol{P}}(\boldsymbol{r},t) \tag{1}$$

$\tilde{P}$: Polarisation of the material

ε_0: Electric field constant

c: Speed of light

The relationship between polarisation and field strength is non-linear and is described by the following equation:

$$\tilde{P}(t)=\varepsilon_0\cdot\left(\chi_1\cdot E(t)+\chi_2\cdot E(t)^2\right) \tag{2}$$

χ_1, χ_2: First- and second-order susceptibilities

Correspondingly, an electric field oscillating at a frequency f and described by the equation

$$E(t)=E_0\cdot\exp(i\cdot 2\pi\cdot f\cdot t) \tag{3}$$

produces polarisation comprising two components. The component

$$\tilde{P}_1(t)=\varepsilon_0\cdot\chi_1\cdot E_0\cdot\exp(i\cdot 2\pi\cdot f\cdot t) \tag{4}$$

oscillates at the original frequency f and describes how the speed of light changes inside the material. The component

$$\tilde{P}_2(t)=\varepsilon_0\cdot\chi_2\cdot E_0^2\cdot\exp(i\cdot 2\pi\cdot 2f\cdot t) \tag{5}$$

oscillates at double the frequency, 2f, and acts as a source for a new component of the electromagnetic field in accordance with equation (1).

When regarded at photon level, this means that two photons with a frequency f are converted into one photon with a frequency $2f$ (see Figure 1).

Due conservation of momentum, the yield here is especially large if the mismatch in phases closely approximates to zero.

$$\Delta k\cdot\frac{L}{2}=\left|2\cdot\frac{2\pi}{\lambda_f}-\frac{2\pi}{\lambda_{2f}}\right|\cdot\frac{L}{2}=\frac{2\pi}{c}\cdot f\cdot L\cdot\left|n_f-n_{2f}\right| \tag{6}$$

L: Length of resonator

λ_f, λ_{2f}: Wavelengths in the material at the original frequency and double the frequency

The refractive indices of the material n_f und n_{2f} should therefore match as far as possible. This can be achieved in birefringent materials with a high degree of anisotropy in three dimensions if they are suitably aligned (see Fig 2). As a consequence, the yield depends on the spatial alignment of the frequency-doubling material.

The power density P_{2f} of the new radiation has a quadratic relationship with the power density P_f of the fundamental radiation. The following applies:

$$P_{2f}=P_f^2\cdot\frac{L^2}{A}\cdot C\cdot F\left(\Delta k\cdot\frac{L}{2}\right)\quad\text{where}\quad F(x)=\left(\frac{\sin x}{x}\right)^2 \tag{7}$$

A: Cross-sectional area of resonator

C: Material constant at the given wavelength

In this experiment, a crystal of $KTiOPO_4$ is used to generate green light with a wavelength of 532 nm from the 1064-nm infra-red radiation output by an Nd-YAG laser by means of frequency doubling. The crystal is suitable in a number of respects, such as its strongly non-linear optical characteristics, and its low absorption of radiation at the original frequency and double the frequency.

EVALUATION

To prove that the output depends on the square of the primary power P_f, use is made of the fact demonstrated in the previous experiment that the power depends on the laser diode's injection current I.

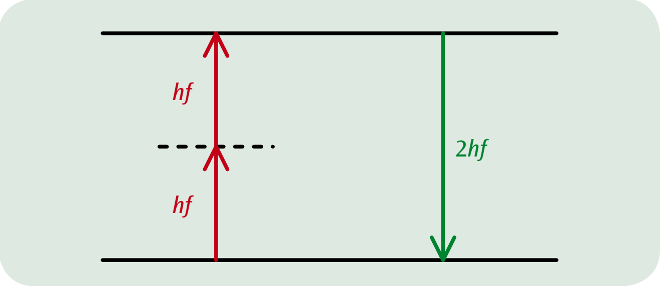


Figure 1: Schematic representation of frequency doubling.

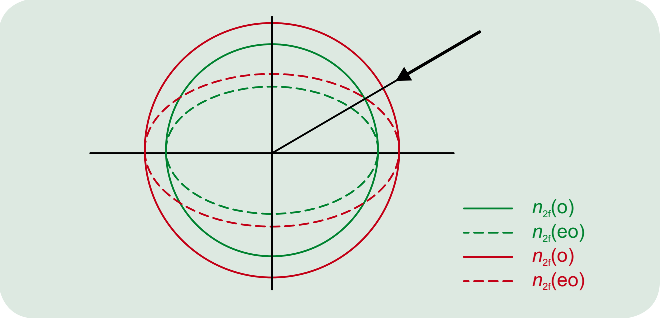


Figure 2: Schematic representation of phase matching through use of birefringence in the material.

n(o): Refractive index for ordinary ray

n(eo): Refractive index for extraordinary ray

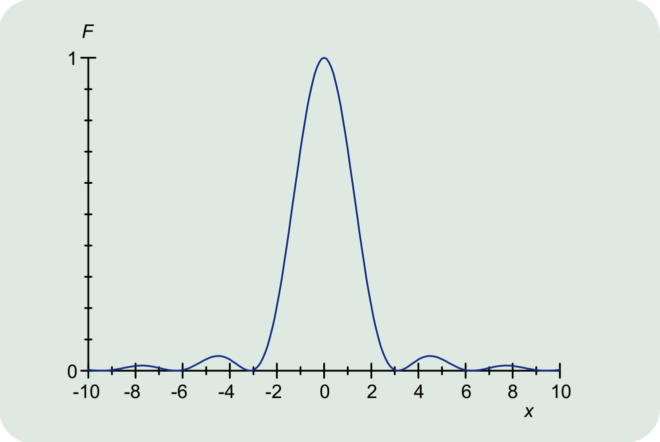


Figure 3: Representation of the function $F(x)$