HeNe Lasers in Barcode Scanners:

A Computational Physics Perspective

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Outline

1- Main principles of a HeNe laser:

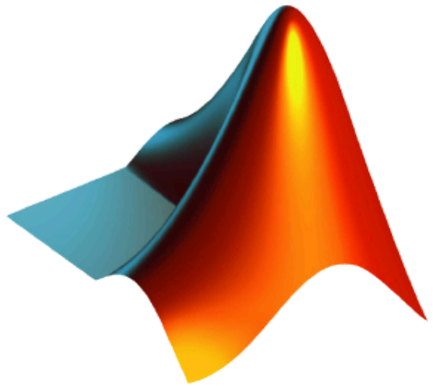
- Population inversion of active medium.
- Laser cavity modes.
- Cavity design.
- Light beam inside the optical cavity.
- ABCD matrix and stability analysis.

2- Using HeNe lasers in barcode scanners:

- How do barcodes work?
- The design of laser scanners.
- Decoding barcodes.

3- Advantages and Disadvantages.

4- Conclusion.



MATLAB

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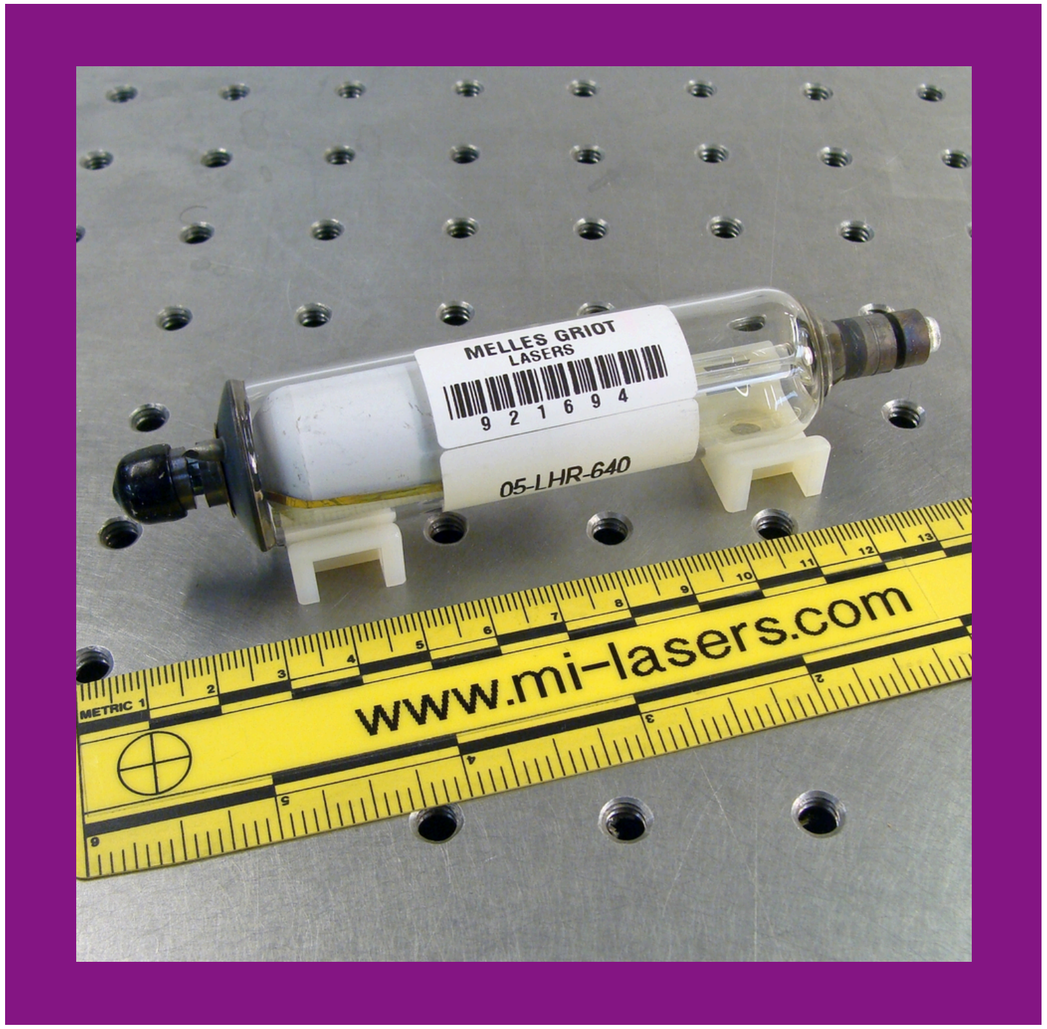


Image source: www.mi-lasers.com

Melles Griot 05-LHR-640 HeNe Laser Tube

SPECIFICATIONS [1]:

- Output Power: 0.5 mW minimum
- Wavelength: 632.8 nm RED
- Polarization: Random
- Mode: TEMoo
- Operating Voltage: 1180 VDC.
- Start Voltage: 8 KV
- Operating Current: 3.5-4.8mA, 4.5mA Ideal
- Dimensions: 5.0″ (127 mm) long x 1.0″ (25.4 mm) diameter.

python™

MATLAB

Population Inversion of Active Medium

- Gain medium of HeNe lasers is a He and Ne mixture of 5:1 – 20:1 ratio [2].
- Excited He atoms collide with Ne atoms exciting them to the 5s state.
- The transition from 5s to 3p state emits photons of 632.8 nm wavelength as in the Figure [3].

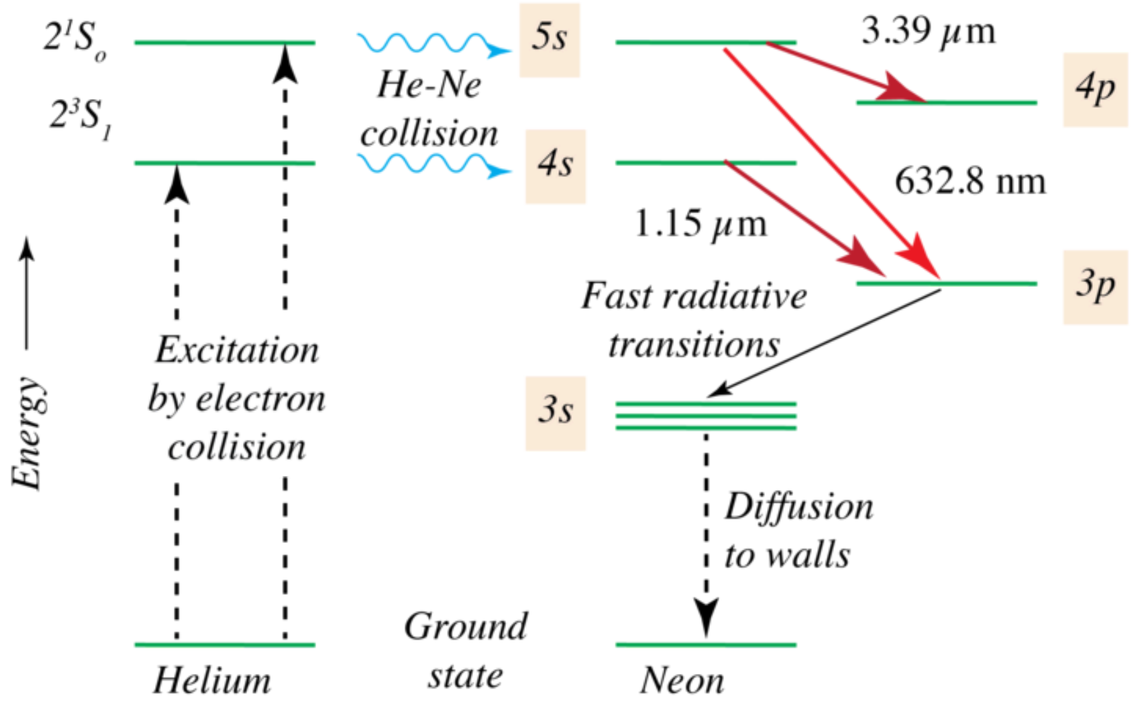
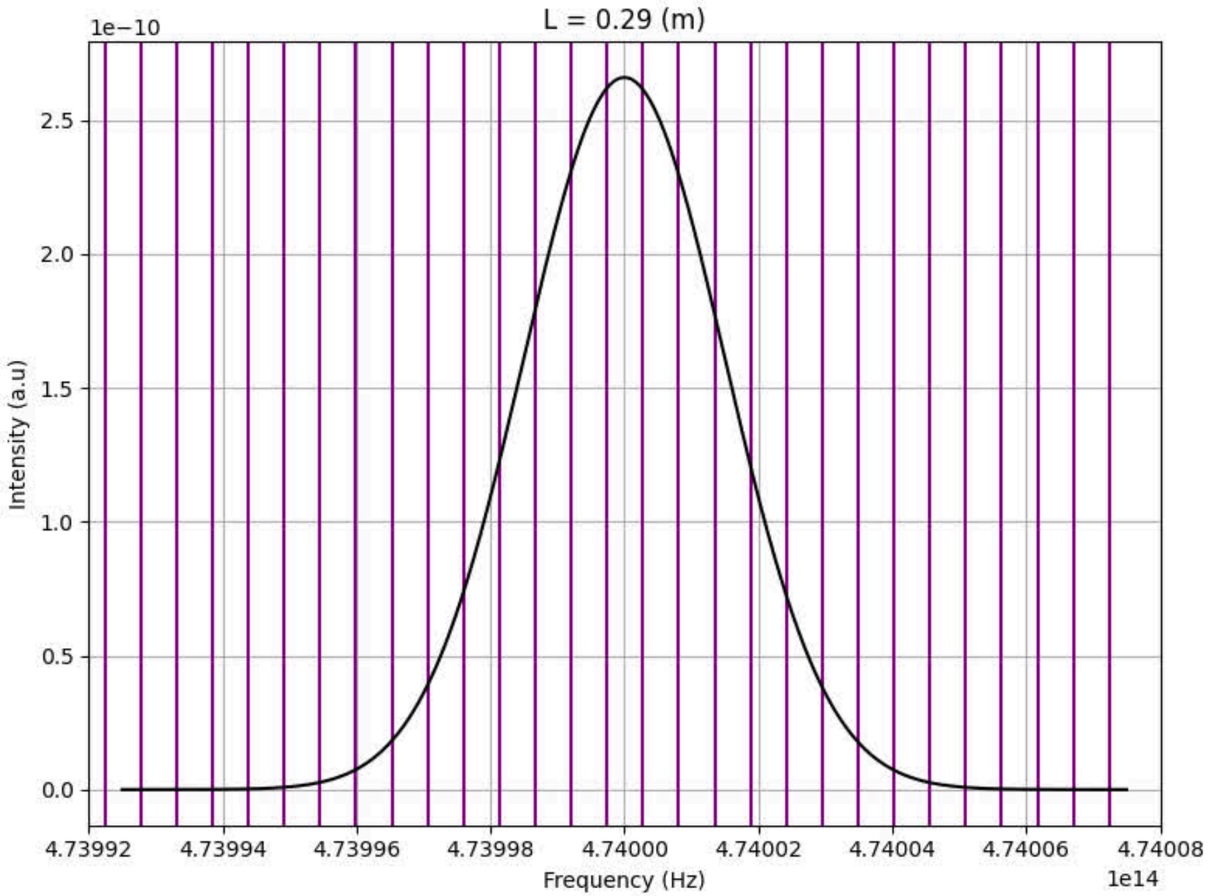


Image source: en.wikipedia.org

Laser Cavity Modes

- The gain medium constrains the lasing modes allowable in an optical cavity.
- Increasing the length of the cavity allows for more modes to be supported by the cavity.

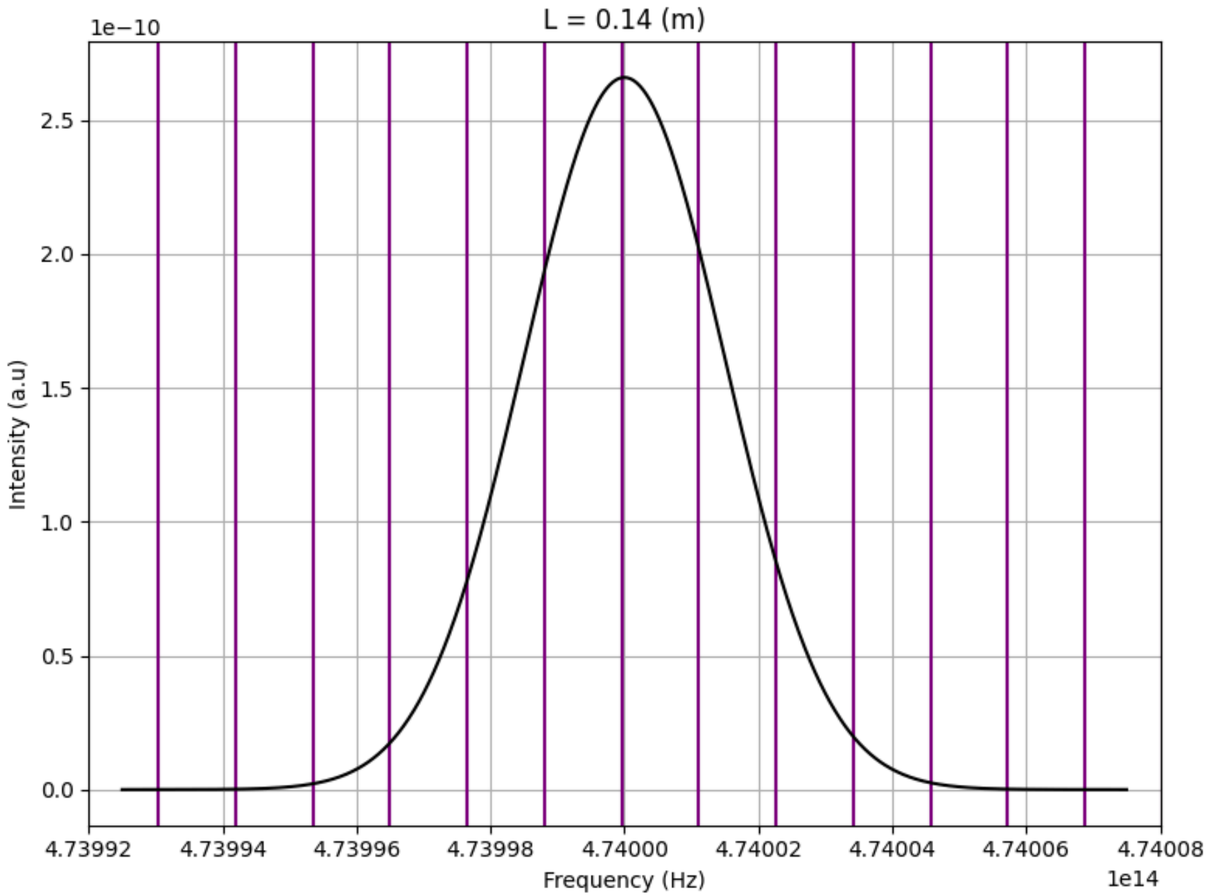


Laser Cavity Modes

- Typically, the barcode scanning lasers have 10-13 cm length tubes [4]. For the Melles Griot tube l = 12.7 cm and the cavity is assumed to have L = 0.14

- For such a cavity, around 7 longitudinal modes exist within the cavity.

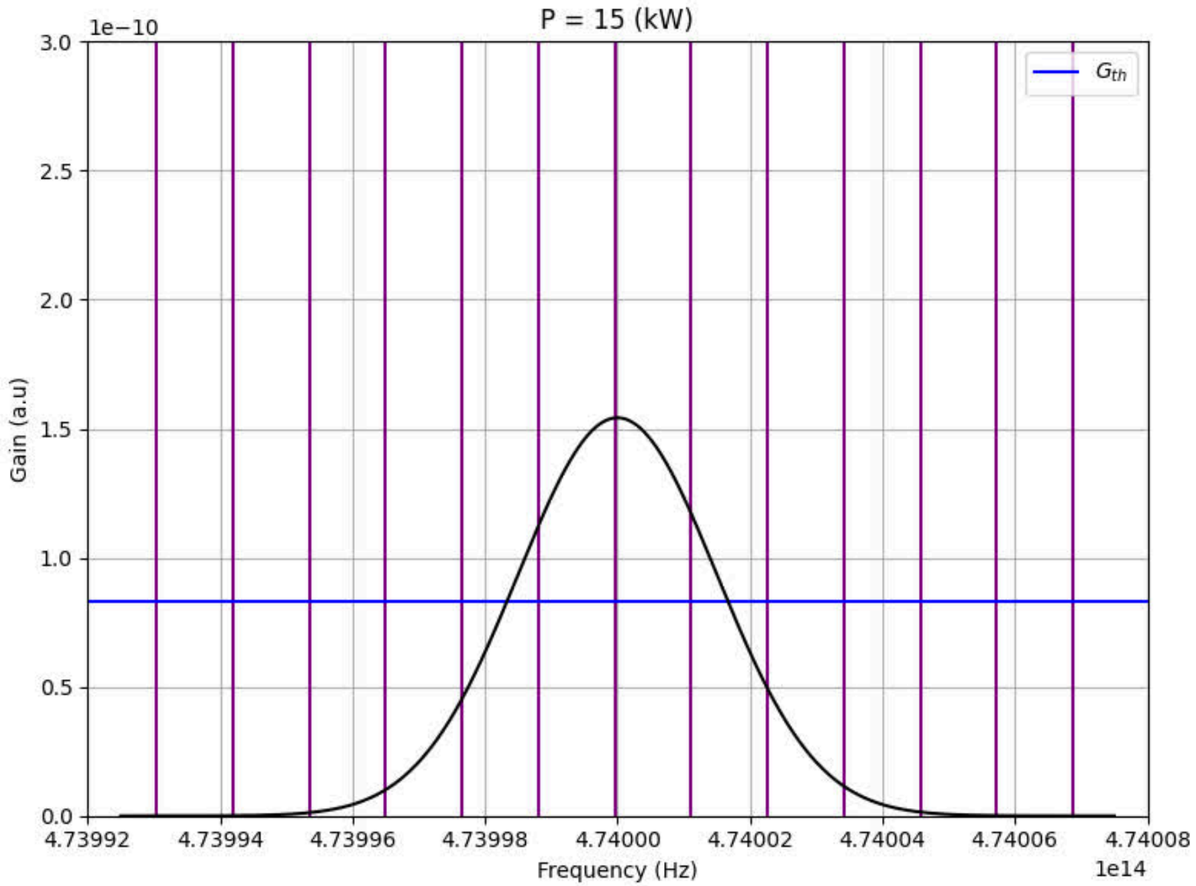
Then how do we get a single mode continuous laser in barcode scanners?



Laser Cavity Modes

- For homogeneous medium, as the pumping power increases, the gain of the central line hits the threshold gain first [5].

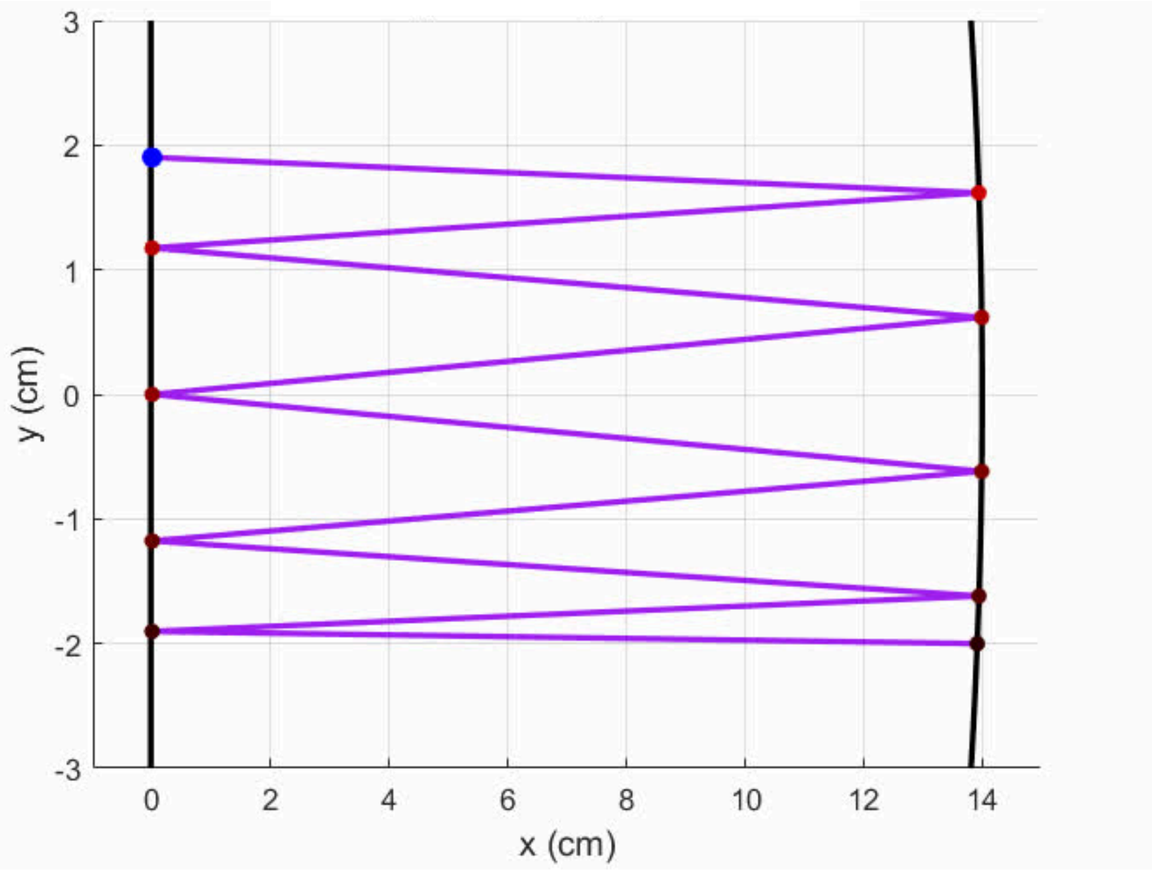
- As the central line mode gets amplified and the saturates back, the gain function clamps around it [6].



Light Beam Inside the Optical Cavity

- Some HeNe cavity designs involve one parallel and one spherical mirror. The radius of curvature of R2 = 24 cm lies in the typical range [4].

- The beam bounces back and forth in a stable cavity.



*Note: the animation here was not done using the corresponding theta and alpha values in r_s = r_m*sin(theta*s + alpha) of this laser cavity.

Cavity Design

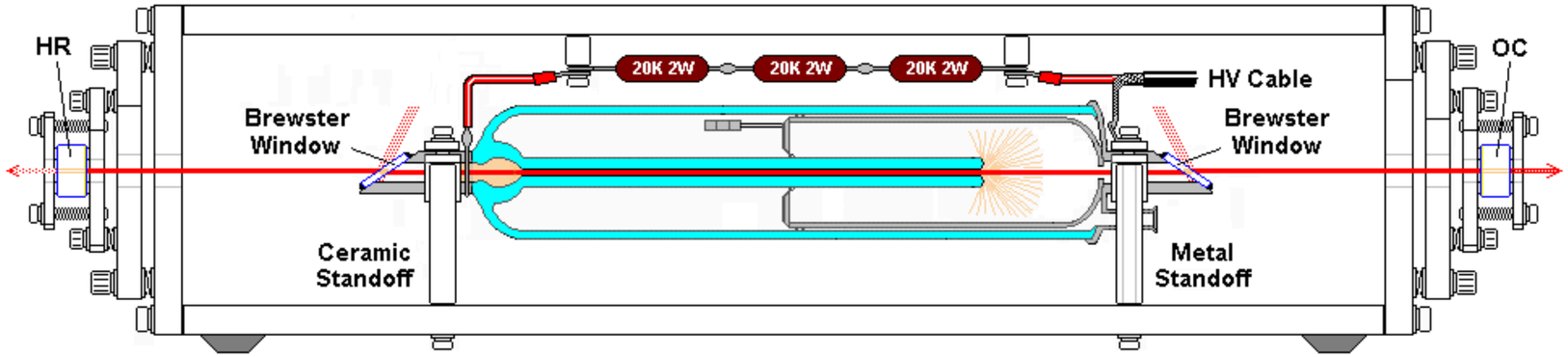


Image source: www.experimental-engineering.co.uk

- OC almost 100% reflectivity, HR around 99% reflectivity [4].
- Brewster window is used to prevent reflection losses.
- Cheaper and easily designed cavity consist of one flat and another spherical mirrors.

Is this cavity stable?

ABCD Matrix and Stability Analysis

```
% The ABCD matrices:
Mr1 = [1, 0; -2/R1, 1]; % Mirror 1
Mr2 = [1, 0; -2/R2, 1]; % Mirror 2
MB = [1, t/nb*cos(atan(nb/nc)); 0, 1]; % Brewster mirror
Ma = [1, La/na; 0, 1]; % Active medium path
Mc = [1, Lc/nc; 0, 1]; % Cavity path

% Full ABCD matrix of a round trip:
Mf = Mr1*Mc*Ma*MB*Mc*Mr2*Mc*MB*Ma*Mc;

% Is the cavity stable (|(A+D)/2| < 1)?
A = Mf(1,1);
D = Mf(2,2);

if abs((A+D)/2) < 1
    disp("The cavity is stable!")
else
    disp("The cavity is NOT stable!")
end
```

```
% Constants:
R1 = 10000; % radius of curvature of the first mirror
R2 = 24; % radius of curvature of the second mirror
nb = 1.5; % Brewster mirror index of refraction
na = 1.03; % Active medium index of refraction
t = 0.0001; % Thickness of Brewster mirror
nc = 1; % Index of refraction of the cavity
La = 12.7; % Path length in the active medium
Lc = 0.5; % Path length in the cavity
```

```
>> stability
The cavity is stable!
>>
```

How do Barcodes Work?

- 1-D Barcodes are a set of black and white horizontal lines of varying width and spaces. These lines store information like price, quantity, manufacturer, etc [7].

- Many types and systems have different standards for the form of the lines and characters of the barcode.

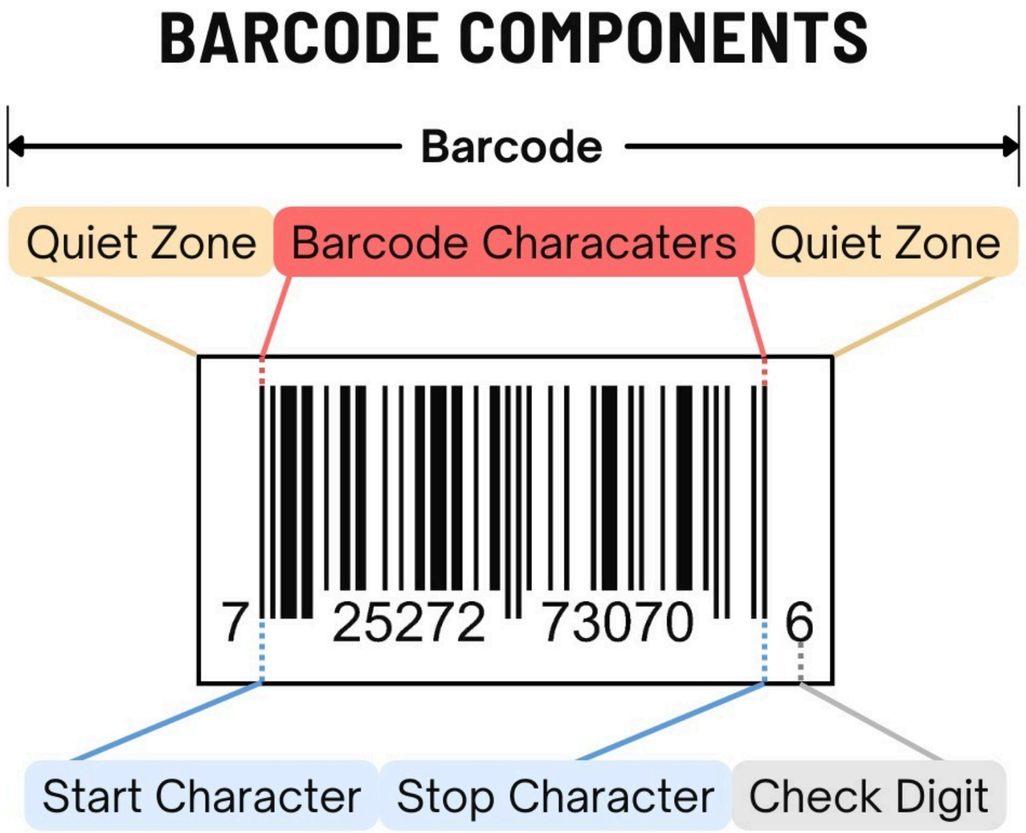
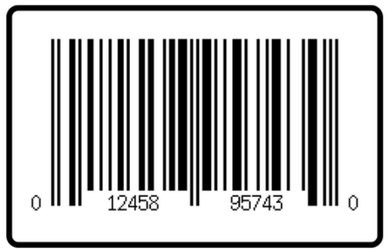


Image source: tritonstore.co.nz

How Do Barcodes Work?

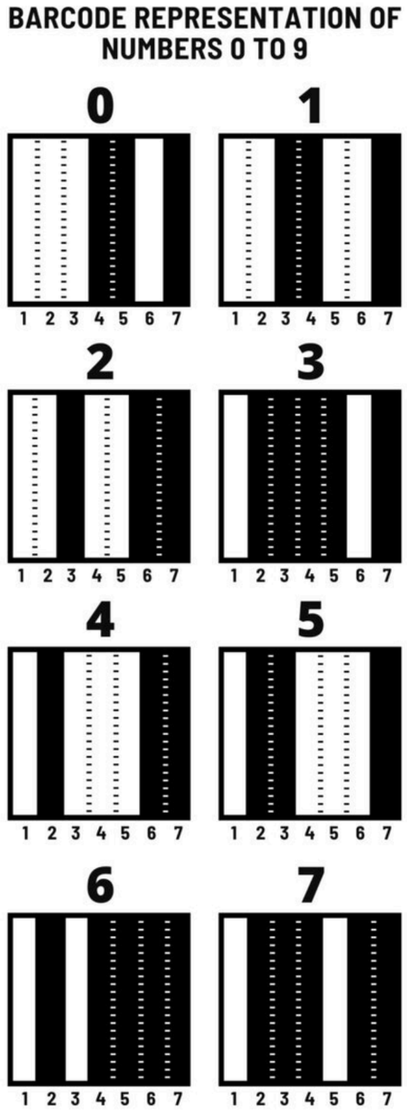
- UPC, Code 39, EAN, Codabar, and others are common types of linear barcodes used today.
- The lines of a barcode are representations of numbers between 0 and 9 that are defined with binary numbers (0s and 1s) [8].

UPC Barcode



Code 39

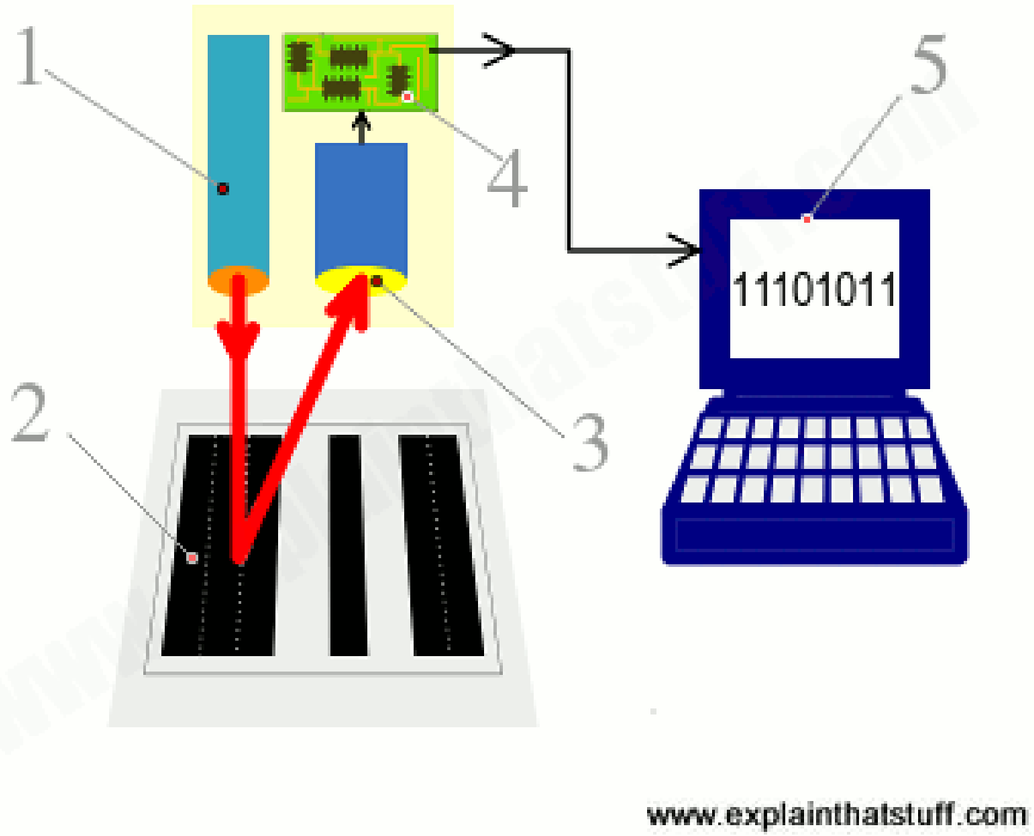
EAN Barcode



Images source: tritonstore.co.nz

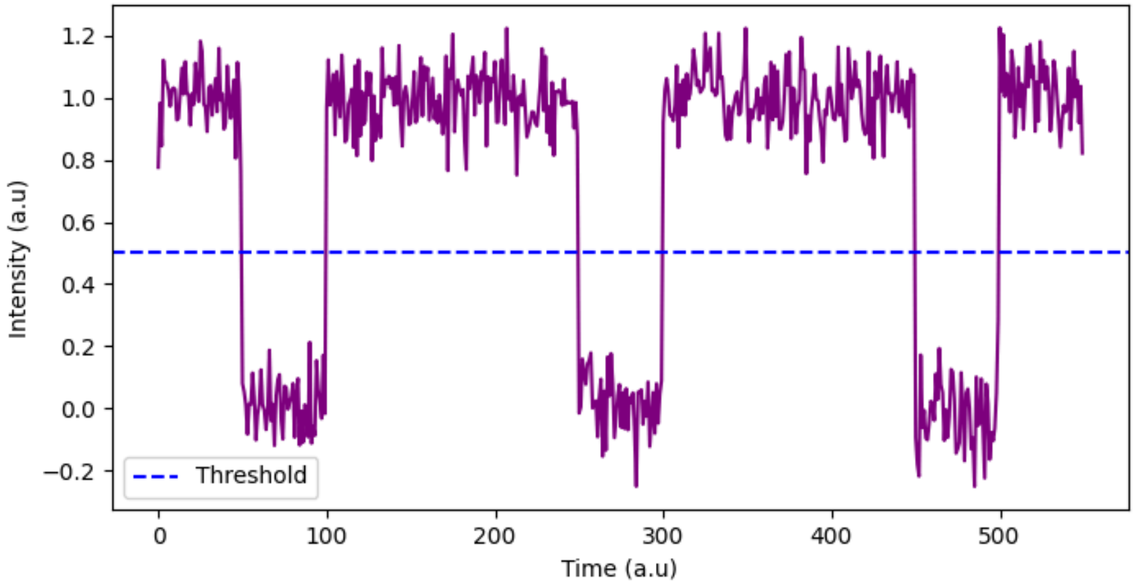
The Design of Laser Scanners

- Laser barcode scanners consist of four main components: a laser light, a sensor, mirrors and lenses, and a decoder [8].
- The intensity of the reflected laser beam onto the detector allows the device to interpret the barcode and extract its information [9] & [10].



Decoding Barcodes

- The HeNe laser scanning the barcode.



- The intensity of light received by the photosensor.

Advantages and Disadvantages

Advantages [11]

- Affordable.
- Easy to design.
- Provide stable output power.
- Great for long range scanning.
- Are generally safe (Class I).
- Can have small designs.
- Long lifetime.

Disadvantages [10] & [12]

- Bad alignment can cause reading issues.
- Reflective surfaces can interrupt the signal.
- Fragile (because of the laser tube).
- Accompanies comparatively large scanners (compared to diode lasers).

Conclusion

- Barcode scanners are widely used devices in many industries.
- Many important physical principles are involved with the production of the HeNe laser beam.
- The basic elements of a barcode scanner are: laser light, a sensor, mirrors and lenses, and a decoder.
- Even though HeNe lasers scanners are functional, diode scanners are now more abundant.

Thank You!

Resources

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