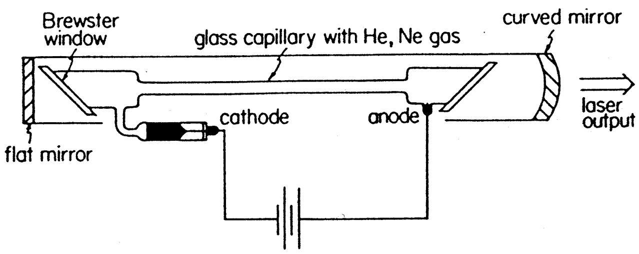
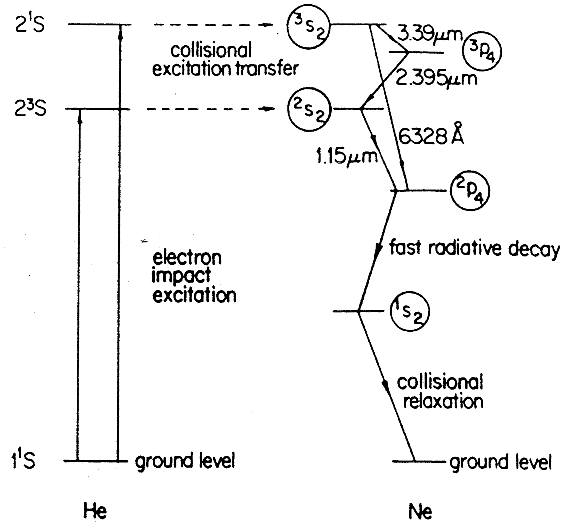
B. Electrical Pumping

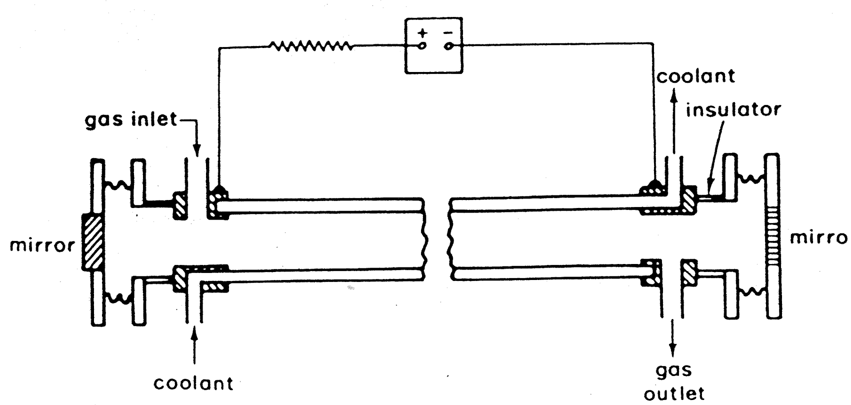
1) He-Ne



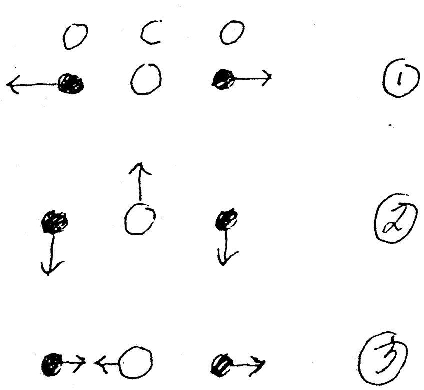


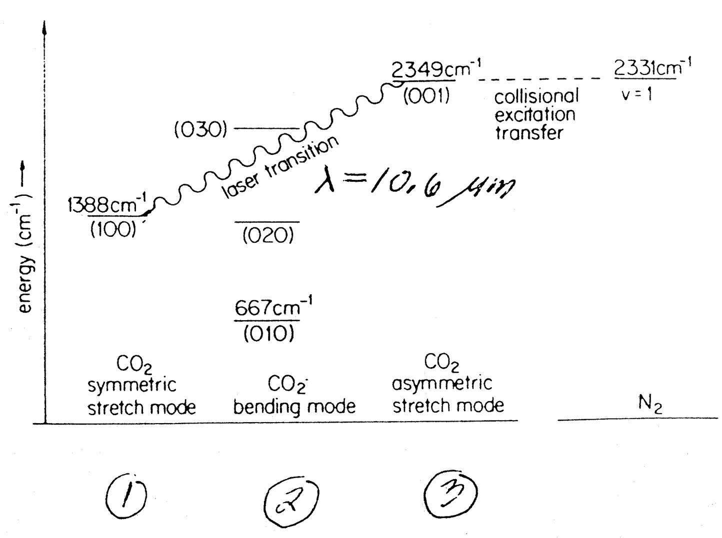
* inexpensive
* low power (few mW)
* first gas laser to oscillate (at 1.15 μm) (Javan, 1961)
* CW
* used for alignment, scanners, pointers

2) CO_2

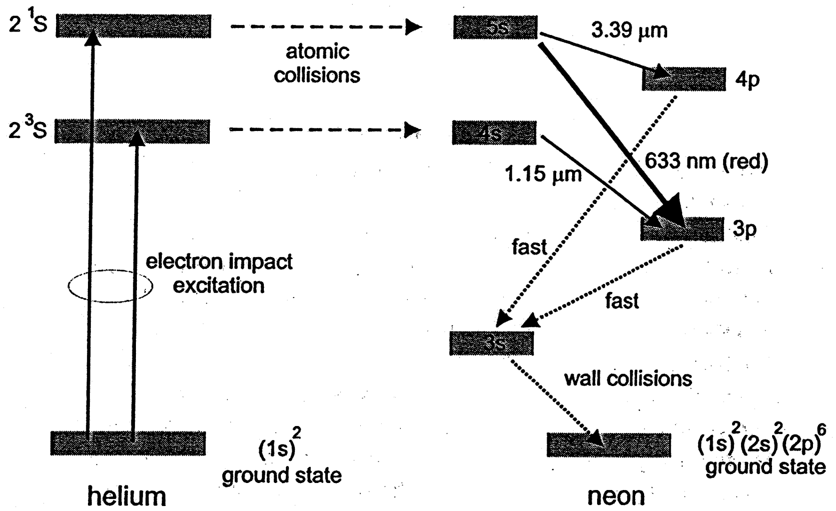


* vibrational
* high power
* CW or pulsed
* efficient (20%)





He-Ne laser (neutral gas)



* small $\Delta\nu = 1.7$ GHz
* Doppler broadened
* Optical pumping is inefficient
* Lasing in Ne -- He only there to facilitate pumping.
* gain at 3.39 μm suppressed by mirrors

Typical parameters:

He : Ne ratio ~ 5:1 (few torr) 1 atm ≈ 760 torr

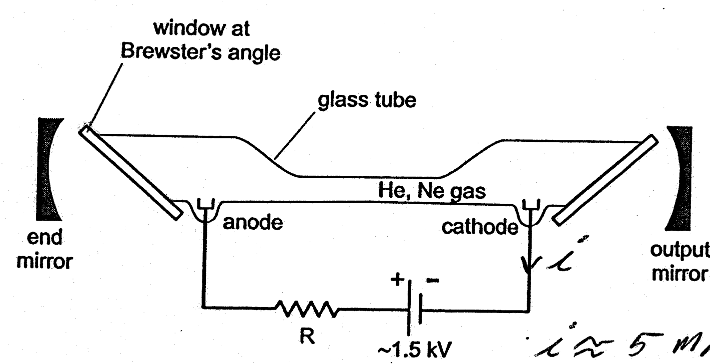
$\tau_{21} \sim 100$ ns $\sigma_{21} \simeq 3 \cdot 10^{-13}$ cm^2

$\tau_{10} \sim 10$ ns

$L = 10\text{-}20$ cm

$N_{2,th} \sim 10^9$ cm^{-3}

$D \approx 2$ mm



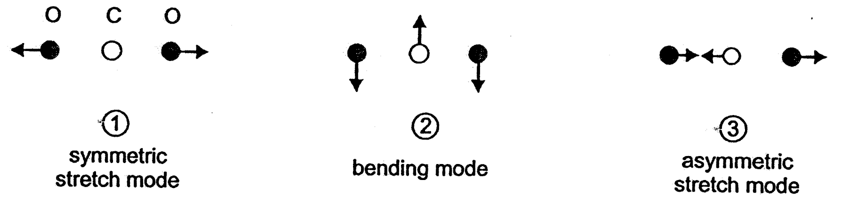
$i \approx 5$ mA

* tube diameter limited by need for Ne-wall collisions to depopulate lower level.
  $P_0 D_{max}$ = constant
* tube length limited by need for high voltage

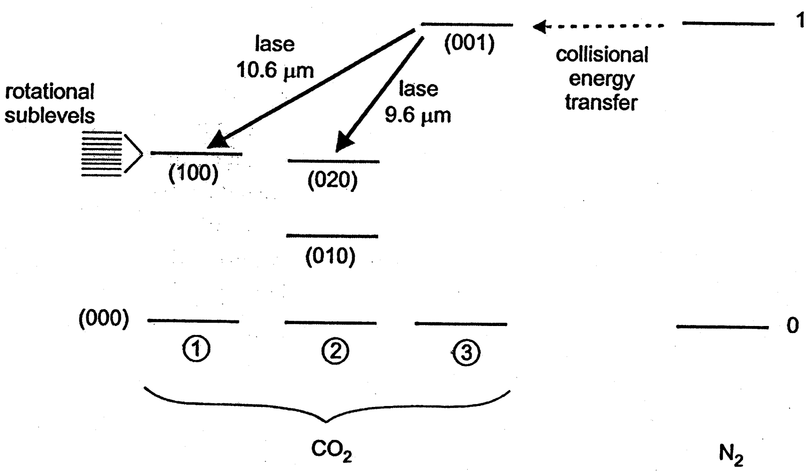
$P_{elec} \simeq 7.5$ W, $P_{optical} \approx 1.5$ mW } $\eta \approx 0.02\%$

CO_2 laser (molecular vibrational transition)

CO_2 molecule vibrational modes ⇒



$f_{V1} = 40$ THz $f_{V2} = 20$ THz $f_{V3} = 70$ THz

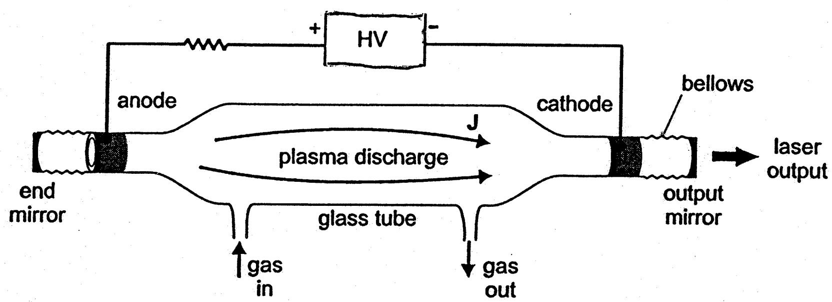


* (020) means two vibrational quanta in mode 2, none in modes 1 and 3.
* Nitrogen facilitates pumping process
* Rotational sublevels allow some tuning

$\Delta E_{vib} \sim 0.1$ eV

$\Delta E_{rot} \sim 10^{-3}$ eV

Longitudinal discharge:

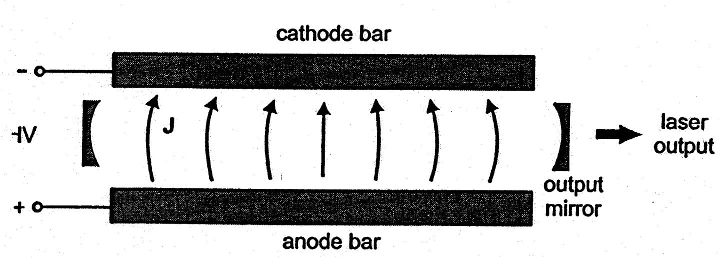


Voltage $\sim 8 \frac{kV}{m}$ at 10 torr

$P_{out} \sim 60 \frac{W}{m}$ at 15 torr

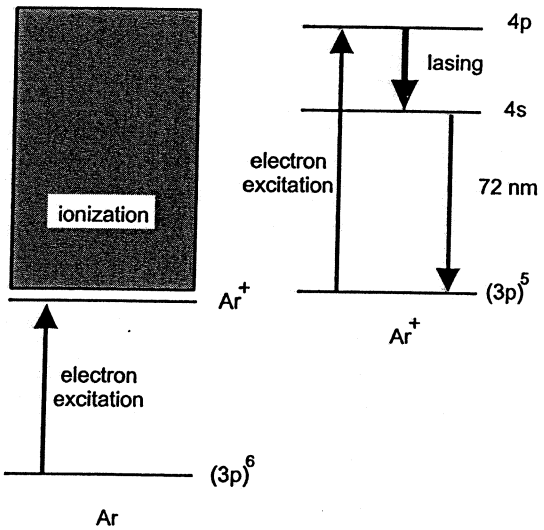
At 1 atm, need $\sim 12 \frac{kV}{cm}$

TEA (Transverse Excitation Atmospheric)



* higher power possible
  10-50 J/liter, $P_{max} \sim 1$ GW
* flow cooling gas transversely

ion laser (Ar^+)



* electronic transition
* high power (20 W)
* low efficiency (10^{-3})
* Applications:
  - pump other lasers
  - laser light shows
  - eye surgery
  - scientific research

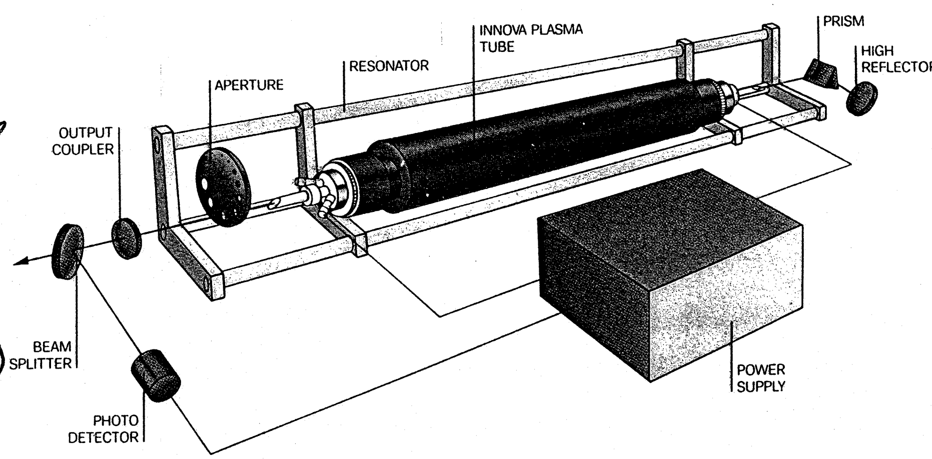
* discreetly tunable (visible)

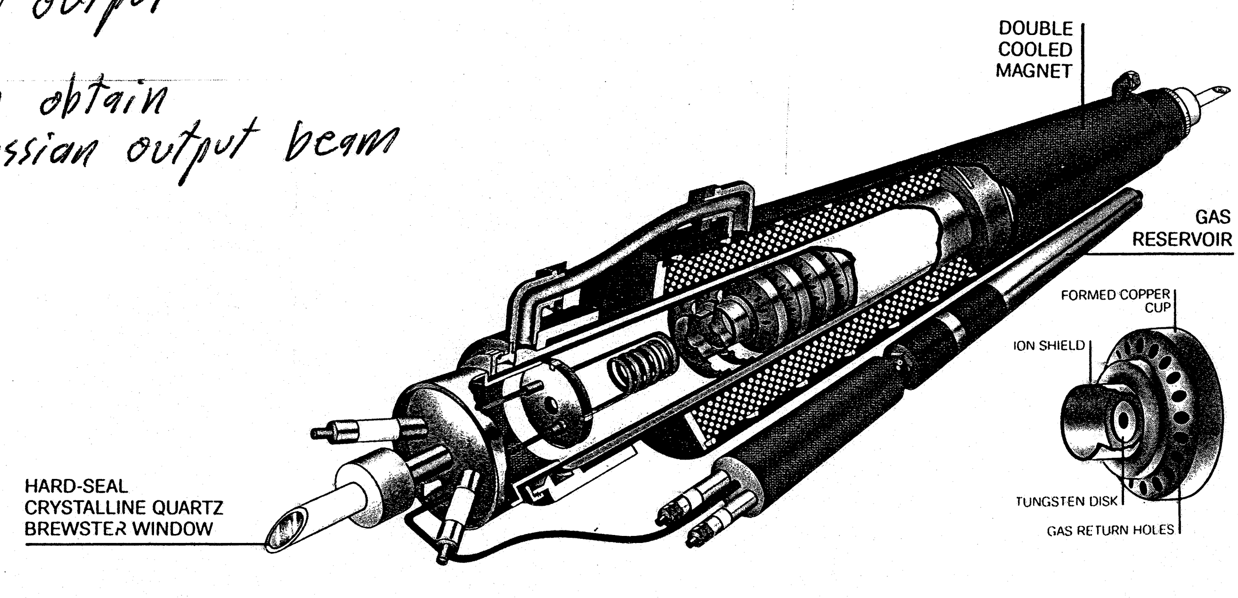
* high i_{th} (two-step excitation)

* can scale up to ≈ 100 W (10–20 W more typical)

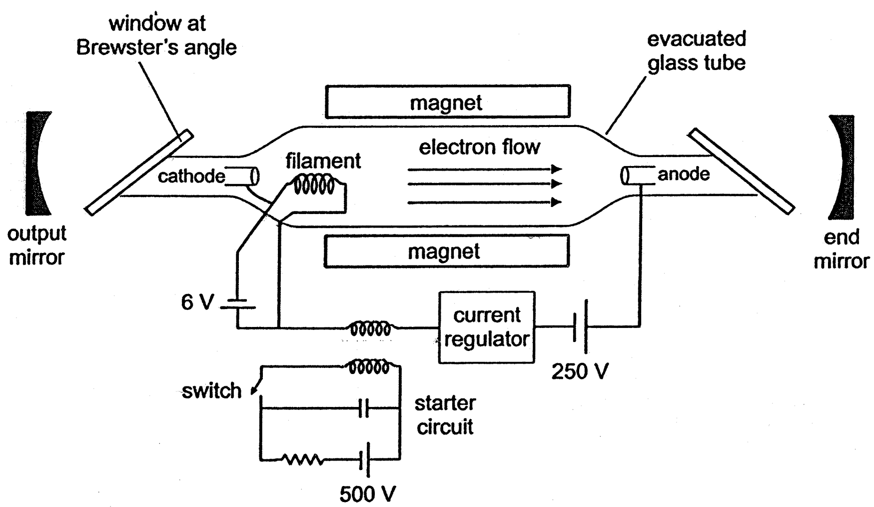
* stable "low noise" cw output

* can obtain Gaussian output beam





Argon ion laser details



* filament "boils off" electrons
* high voltage pulse initiates discharge
* plasma maintained by ~ 250 V
* Brewster windows (low gain)
* high R needed

Typical numbers:

$\lambda = \begin{matrix} 514.5 \text{ nm} \\ 488.0 \text{ nm} \end{matrix} \Big\}$ major lines

$J \sim 10^3 \frac{A}{cm^2}$

$T \sim 3000\ ^\circ K$

$\tau_{21} \simeq 6$ ns (allowed transition)

$\Delta\nu_{inh} \simeq 3.5$ GHz (Doppler)

$L \simeq 1$ m

$N \sim 10^{15} - 10^{14}\ cm^{-3}$

$N_{2,th} \sim 10^{7}\ cm^{-3}$

$\left. \begin{matrix} V_{in} \sim 400 \text{ V} \\ I_{in} \sim 30 \text{ A} \end{matrix} \right\} P_{in} \approx 12 \text{ kW}$

$P_{out} \simeq 5$ W

$\eta \approx 0.04\ \%$

* need flowing water around tube to provide cooling
* Kr^+ laser similar but different λ

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Specifications

OUTPUT POWER SPECIFICATIONS

Argon Ion Laser TEMoo (Watt)

	Model Number		
Wavelength (nm)	2020-03 / 2025-03	2020-04 / 2025-04	2020-05 / 2025-05
Multi-line			
351.1-363.8	0.050 / 0.200	0.075 / 0.300	0.100 / 0.400
457.9-514.5	3.000 / 3.000	4.000 / 4.000	5.000 / 5.000
Single Line[1]			
514.5	1.200	1.700	2.000
501.7	0.200	0.300	0.400
496.5	0.400	0.600	0.700
488.0	1.000	1.300	1.500
476.5	0.350	0.600	0.750
472.7	0.130	0.200	0.300
465.8	0.070	0.125	0.200
457.9	0.200	0.300	0.350
454.5	0.050	0.075	0.120

Krypton Ion Laser TEMoo (Watt)

	Model Number
Wavelength (nm)	2020-11 / 2025-11
Multi-line	
337.4-356.4	- / 0.150
406.7-415.4	- / 0.150
647.1-676.4	0.750 / 0.600
Single Line[1]	
799.3	- / 0.030
752.5	- / 0.100
676.4	0.150 / 0.120
647.1	0.600 / 0.500
568.2	- / 0.200
530.9	- / 0.200
520.8	- / 0.090
482.5	- / 0.045
476.2	- / 0.060
413.1	- / 0.060

Note:
1. Single-line powers for argon lasers are specified at 514.5 nm and 488 nm and for krypton lasers at 647.1 nm and 676.4 nm only. Other powers indicated are nominal. Firm specifications are available with special testing.

PERFORMANCE SPECIFICATIONS

Noise and Stability Characteristics

Noise[1,2] Current Mode	- 0.5% rms
Noise[1,2] Power Mode	- 0.2% rms
Stability[3] Current Mode	- ±3%
Stability[3] Power Mode	- ±0.5%

Beam Characteristics

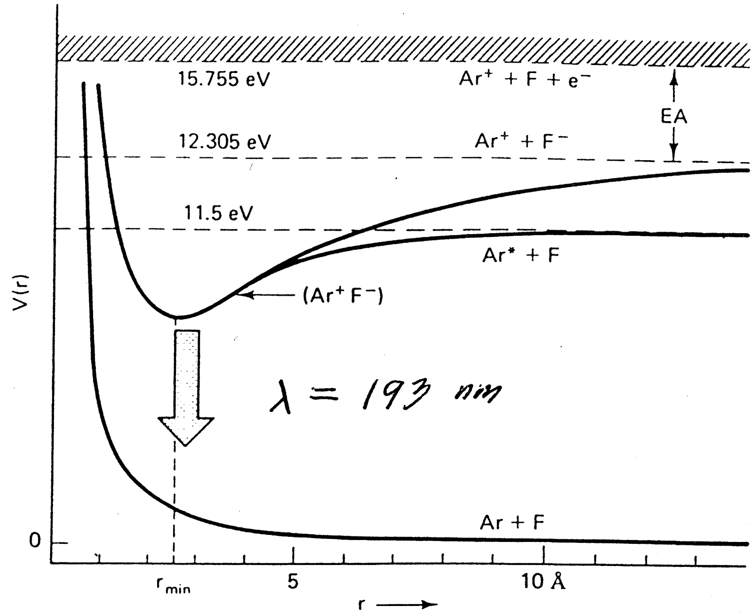
Beam Diameter[4] @ $1/e^2$ points	- 1.5 mm @ 514.5 nm
Beam Divergence @ $1/e^2$ points	- 0.5 mrad @ 514.5 nm
Cavity Length	- 1.10 m
Mode Spacing	- 136.1 MHz
Polarization	- Vertical

Water and Electrical Requirements

Power Supply Line	- 3 phase with ground
Voltage	- 208 V (±10%)
Current	- < 48 A, Model 2020[5] < 61 A, Model 2025
Power Consumption	- 17.3 kVA, Model 2020 22.0 kVA, Model 2025
Water Flow Rate	- 9.5 l/min (minimum) (2.5 gal/min)
Water Pressure	- 1.1 - 5.3 kg/cm^2 (15 - 75 psi)

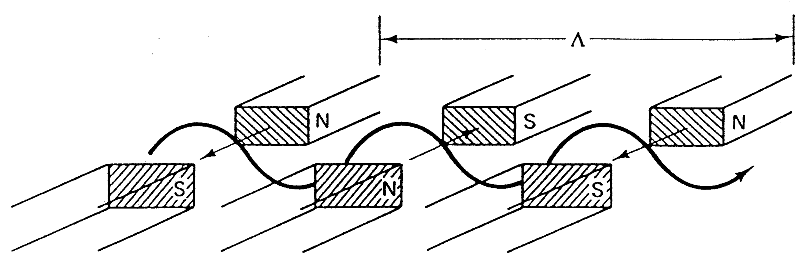
4) eximer (Ar F)

* vibronic
* unbound ground state
* pulsed (Δt ~ 10 ns)
* UV
* high power (100 W)
* moderate efficiency ~ 1 %
* Applications:
  - pump dye lasers
  - photolithography



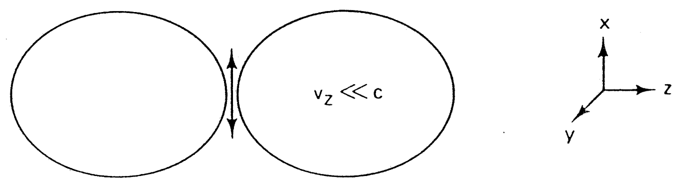
C. Free electron laser

* "pump" is kinetic energy of electron beam



* very broadly tunable

* longer λ lases more efficiently

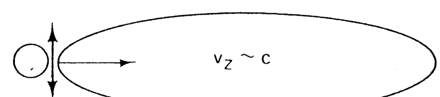


* "wiggler" accelerates electrons

$\beta \equiv \frac{v_z}{c}$

$\gamma \equiv \frac{1}{\sqrt{1-\beta^2}}$

* lasing λ depends on electron energy



$E = \gamma m_0 c^2$

$\lambda \approx \frac{\Lambda}{2\gamma^2}$

$KE = (\gamma - 1) m_0 c^2$