ICRH IN THE CULHAM LEVITRON

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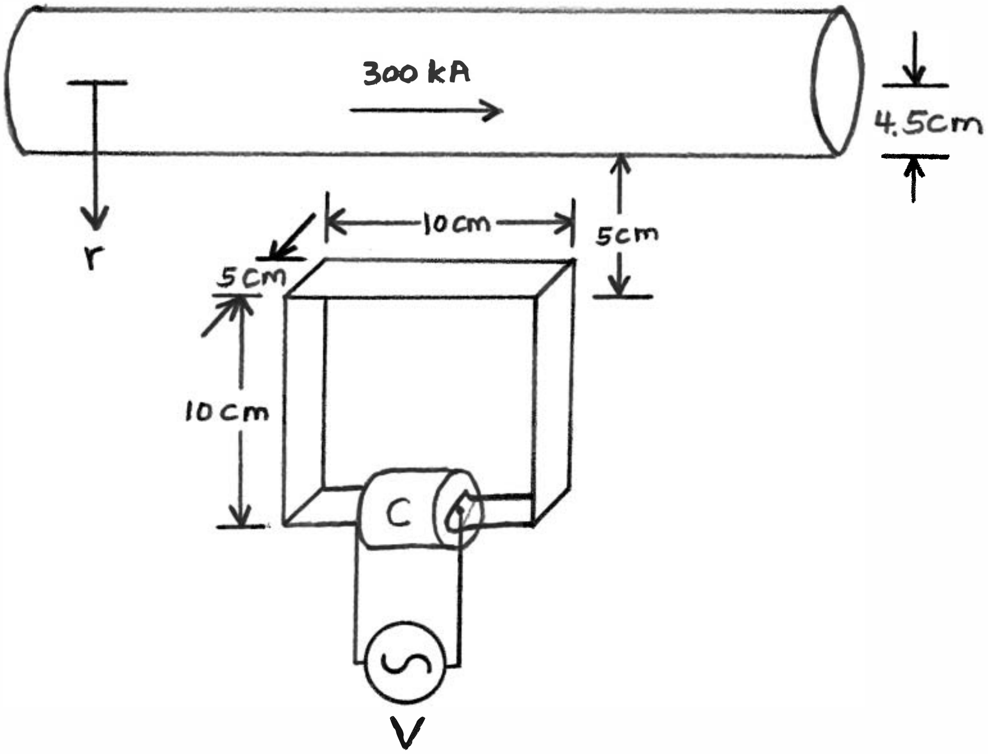
The Culham levitron is in many ways ideally suited for ICRH experiments. Steady state plasmas with densities of ~ 10^{12} cm^{-3} can be produced by ECRH with gas pressures ~ 10^{-6} torr. The plasma has a large aspect ratio with a toroidal field that is normally small compared with the poloidal field and mod-B surfaces which are nearly coincident with flux surfaces. The vacuum chamber wall is a large distance from the plasma and large ports are available. The ring is fully levitated and so obstacle losses would not be present. The purpose of this note is to indicate a preliminary design of an ICRH system that would result in an interesting heating experiment for that device, and to predict the ion temperatures that could be achieved as a function of ICRH power.

The relevant dimensions of the device and proposed coupling structure are shown below:



The plasma density is assumed parabolic:

$$n = n_o \left[1 - \frac{(r-7)^2}{(2.5)^2}\right] \qquad 4.5 < r < 9.5$$

where n_o is taken to be 10^{12} cm^{-3} and r is the distance from the center of the ring in cm. The magnetic field is assumed to be given by

$$\vec{B} = \alpha\, \hat{\phi}/r$$

where α = 60 kG-cm for 300 kA in the ring. From the standpoint of the ICRH, the toroidal field and the toroidal curvature have been neglected. At the density maximum (r = 7 cm), B = 8.57 kG which implies a resonance frequency for protons of 13 MHz.

The coupling structure is estimated to have an inductance of ~ 0.2μ hy and a reactance at 13 MHz of ~ 16 Ω. The capacitor required to tune it to resonance is ~ 750 pF. The coil, assuming copper at room temperature, is estimated to have an ac series resistance of ~ 0.007 Ω . For an rms voltage V on the terminals of the coil, the rms inductive electric field at the surface of the coil in volts/meter is given approximately by V/0.4, and the maximum field at the resonance surface is ~ V/0.8.

The power absorbed by the plasma is given by

$$P_a = \int \vec{j} \cdot \vec{E}\, dV = \frac{\pi}{2} \int n e \overline{E_\perp^2}\, \delta(B-B_o) dV.$$

Assuming that the heating takes place in the near field of the coil (no excitation of waves), the integral can be approximated by

$$P_a \simeq \frac{\pi}{2}\; n_o e \left(\frac{V}{0.8}\right)^2 \left(\frac{10x7x7}{B_o}\right) = 2.24 \times 10^{-16}\; n_o V^2 \text{ watts}$$

where n_o is in cm^{-3} and V is in volts. For $n_o = 10^{12}$ cm^{-3} the plasma represents an equivalent parallel resistance across the coil of

$$R_p = \frac{V^2}{P_a} \cong 4500\ \Omega$$

The coupling efficiency is then $\eta \overset{\sim}{=} 90\%$, and the loaded Q of the circuit is about 250.

For an ion energy confinement time of 1 ms, the power required to produce a 100 eV rise in ion temperature is

$$P = \frac{\Delta kT_i}{\eta \tau_E} \int n\, dV \simeq 500 \text{ watts.}$$

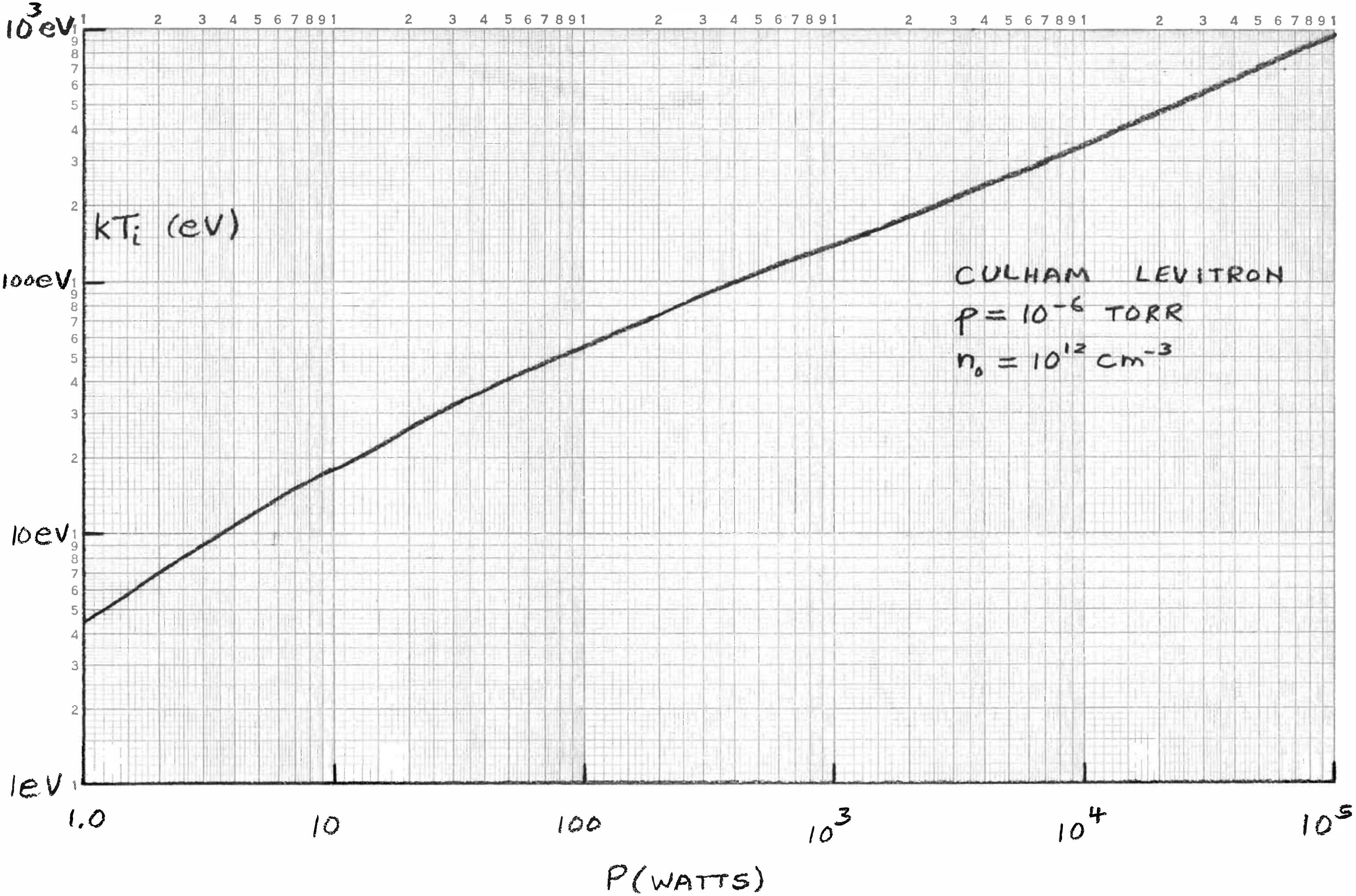
At this power level, the rms coil voltage is ~ 1.4 kV and the circulating current is ~ 100 A. A convenient source of 500 W @ 13 MHz is an amateur radio transmitter which should cost < $1000.

A more careful calculation taking into account charge exchange losses gives the power (in watts) required to produce a temperature T_i (in eV):

$$P = \frac{4.17\text{x}10^{-12} p\ T_i^{3/2}}{e^{0.0582 \sqrt{T_i}}} (1+0.00585\ T_i^{3/2}) \int n\, dV,$$

where p is the neutral pressure in torr. A graph of this equation for $n_o = 10^{12}$ cm^{-3} and $p = 10^{-6}$ torr is given at the end. This estimate may be somewhat optimistic because other losses are surely present, and even the charge exchange loss ignores wall reflux which may be large with these hot ion plasmas.

In conclusion, it appears that an ICRH experiment on the Culham levitron should result in significant ion heating with a modest rf source and coupling structure.


10³eV
100eV
10eV
1eV
kTᵢ (eV)
CULHAM LEVITRON
p = 10⁻⁶ TORR
n₀ = 10¹² cm⁻³
1.0
10
100
10³
10⁴
10⁵
P(WATTS)