Particle acceleration in EXB configuration

A. Fruchtman

H.I.T. - Holon Institute of Technology

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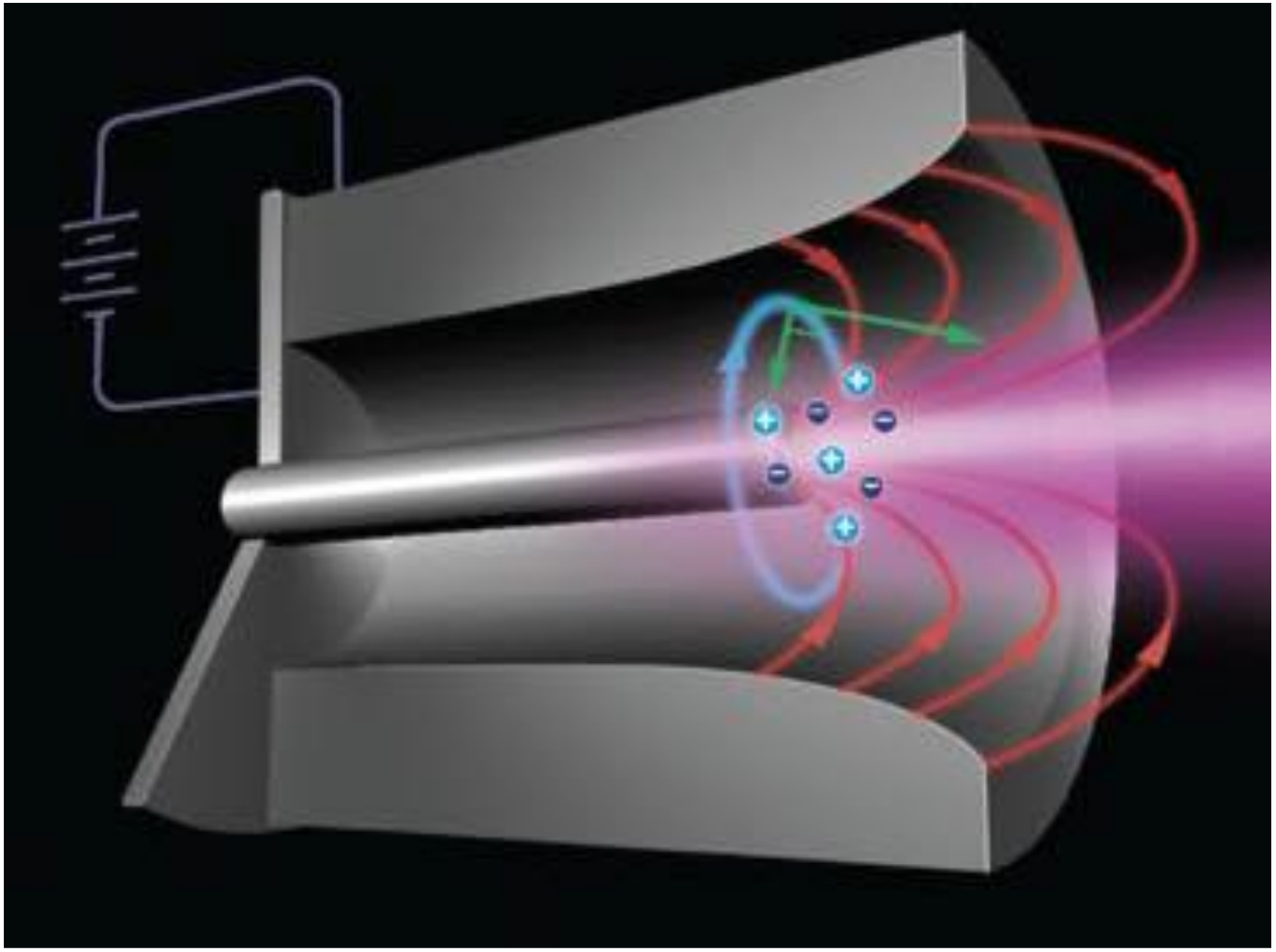
Content

- Crossed electric and magnetic fields and plasma acceleration
- Electrodeless plasma thruster
- Oscillating electric and magnetic fields

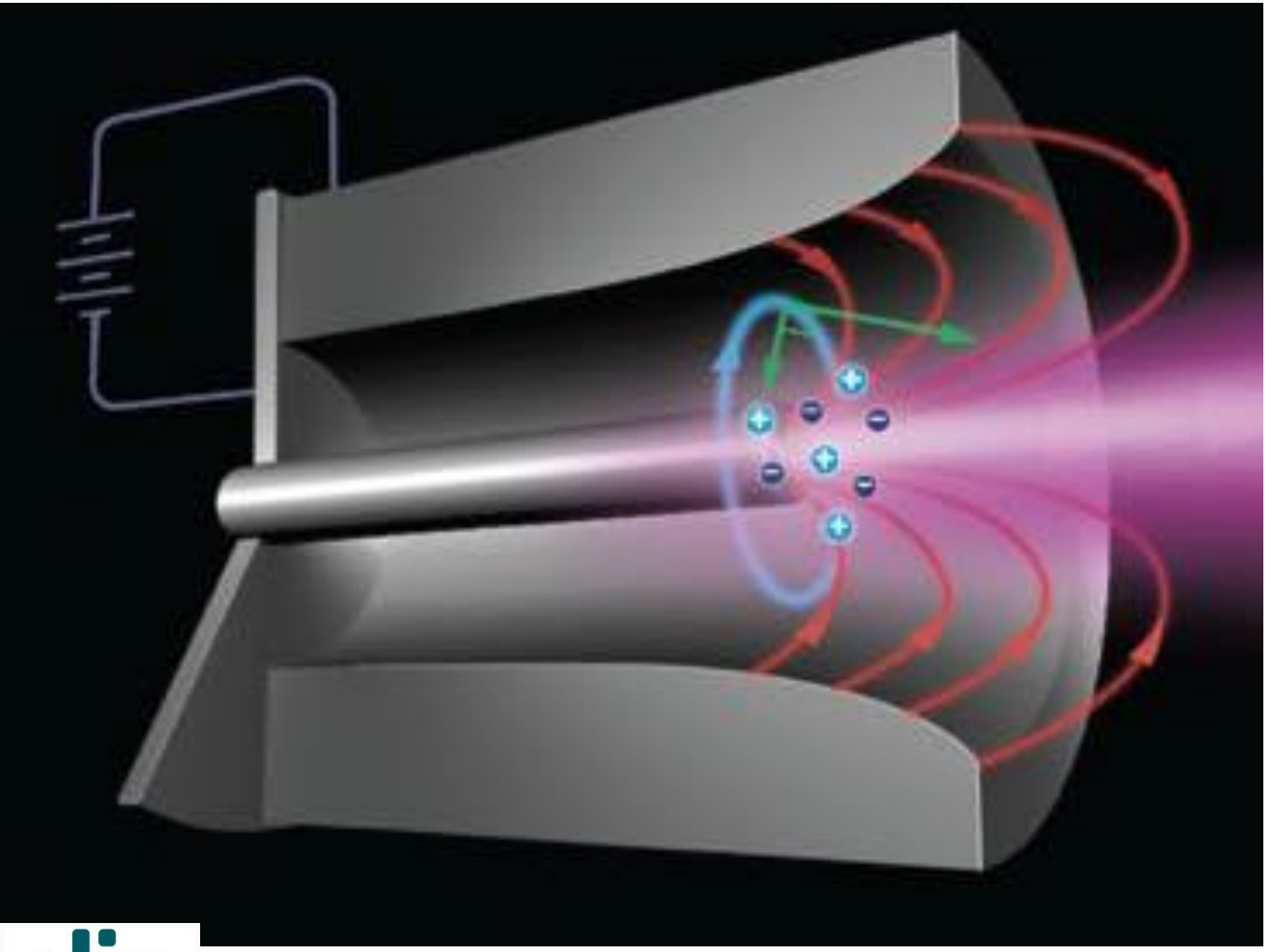
$E \times B$ acceleration

In many accelerators. For example, the Magneto-Plasma- Dynamics (MPD) thruster

Magneto Plasma Dynamics Thruster



Magneto Plasma Dynamics Thruster



$$v_z = \frac{E_r}{B_\vartheta} \quad \textbf{or} \quad j_r B_\vartheta$$

A radial current is driven by an axial Space-charge Electric field.

Electrodes are Needed at the radial Boundaries.

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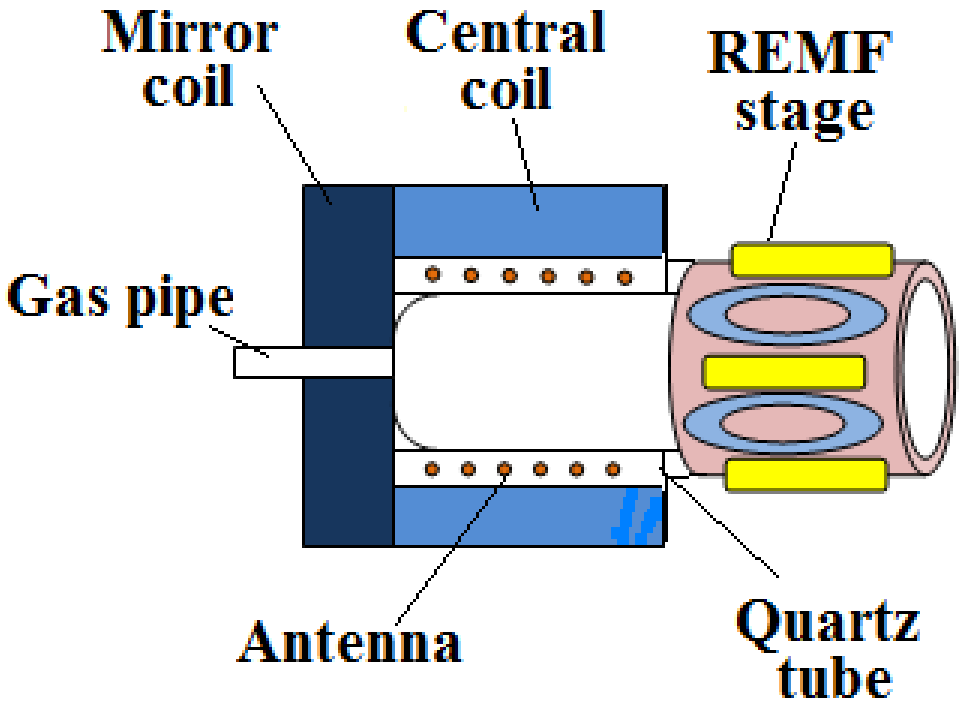
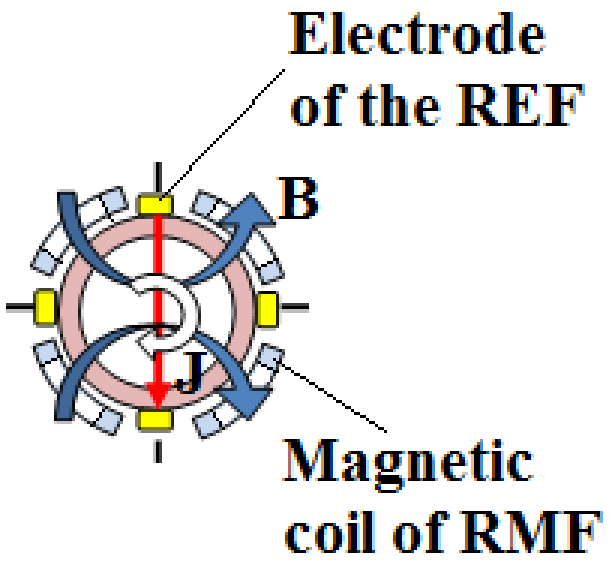
Electrodes - disadvantage

- Erosion that limits lifetime

Oscillating EM fields (no external electrodes)





Equations of motion

$$\vec{E} = \hat{x} E_0 \cos(\omega t) \quad \vec{B} = \hat{y} B_0 \cos(\omega t - \phi).$$

$$\frac{du_x}{d\tau} = s\left[\cos(\tau) - u_z \cos(\tau - \phi)\right],$$

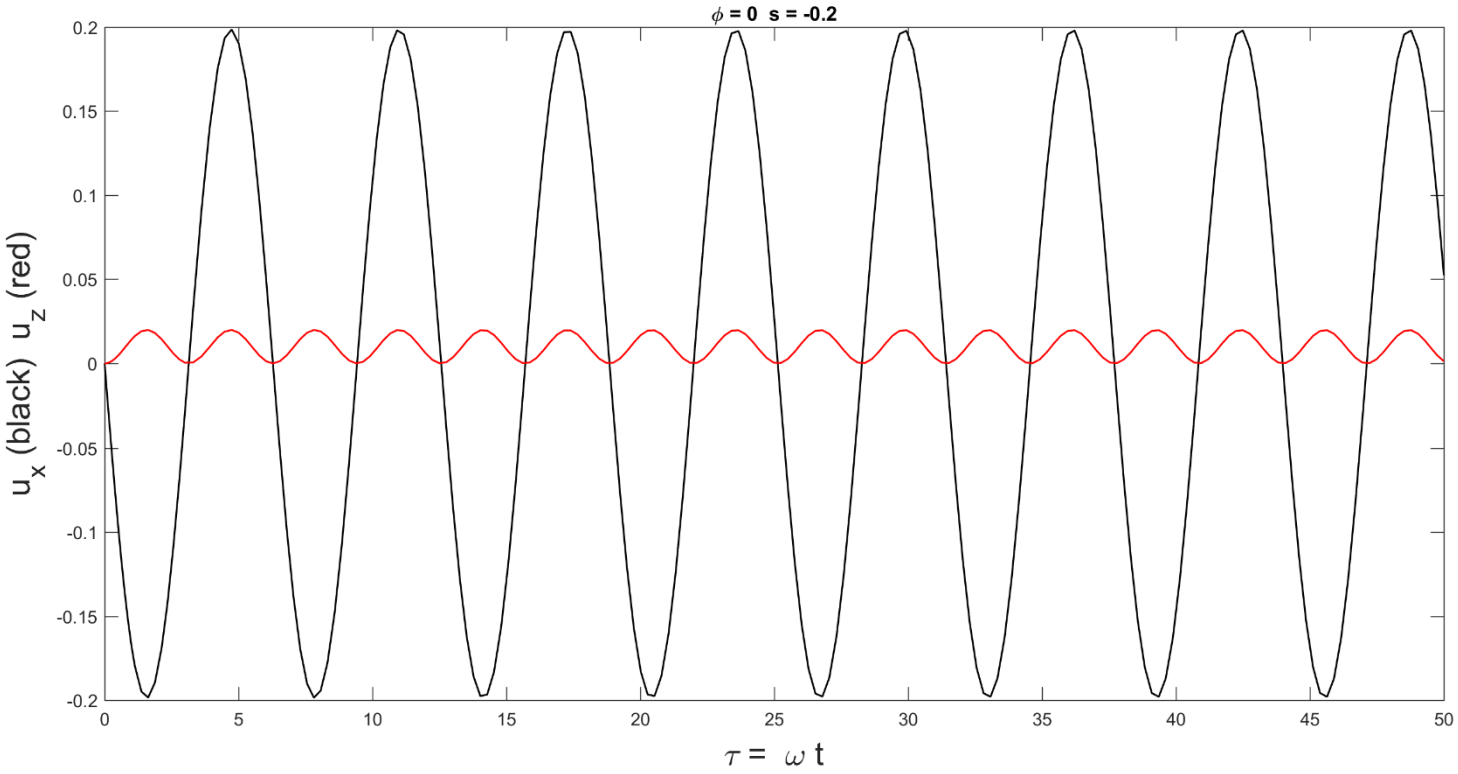
$$\frac{du_z}{d\tau} = s u_x \cos(\tau - \phi).$$

$$\vec{u} \equiv \frac{\vec{v}}{E_0 / B_0} \qquad \tau \equiv \omega t \qquad s \equiv \frac{eB_0}{m\omega} = \frac{\omega_c}{\omega}.$$

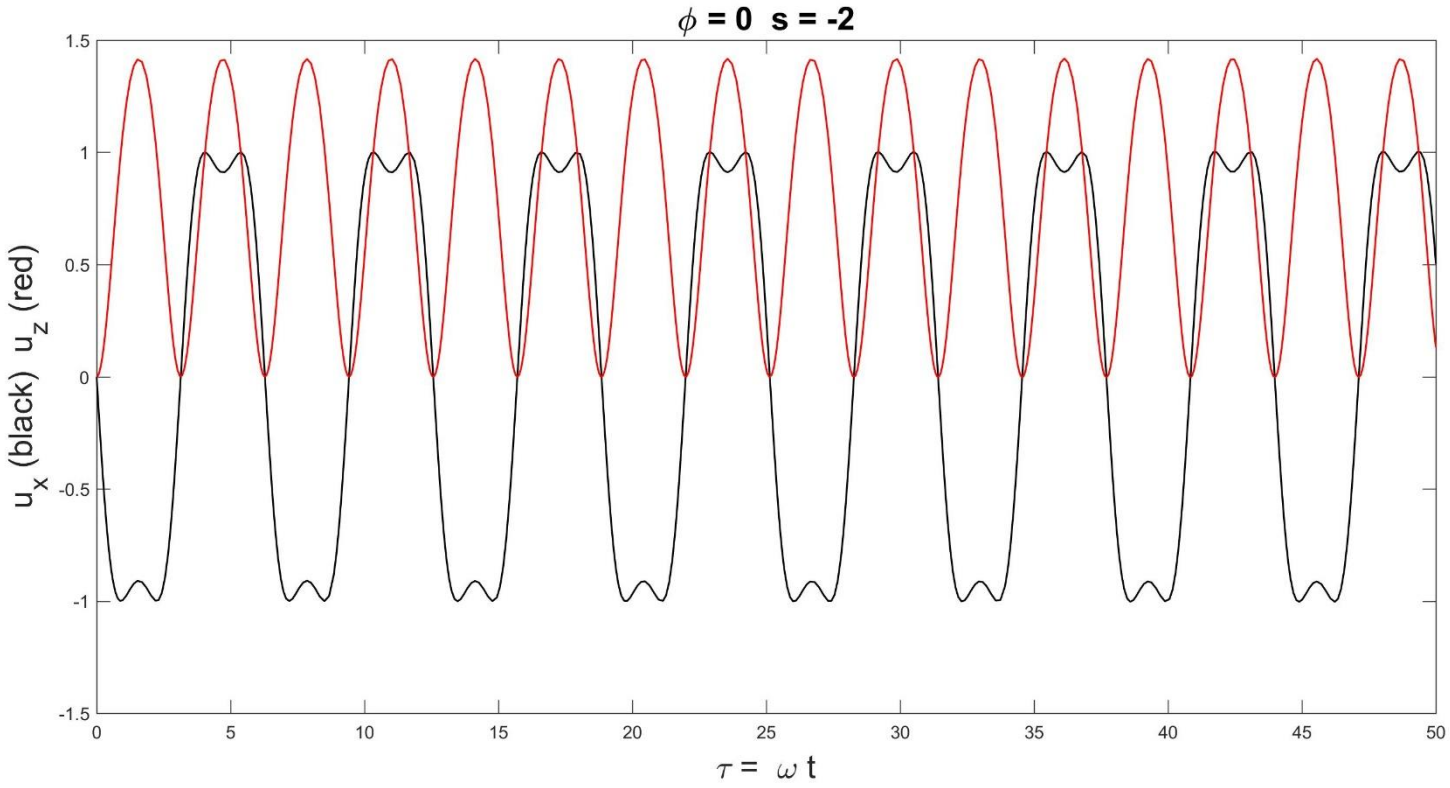
Two cases

- As in a travelling wave: $\phi = 0$
- As in a reflected decaying wave: $\phi = \frac{\pi}{2}$

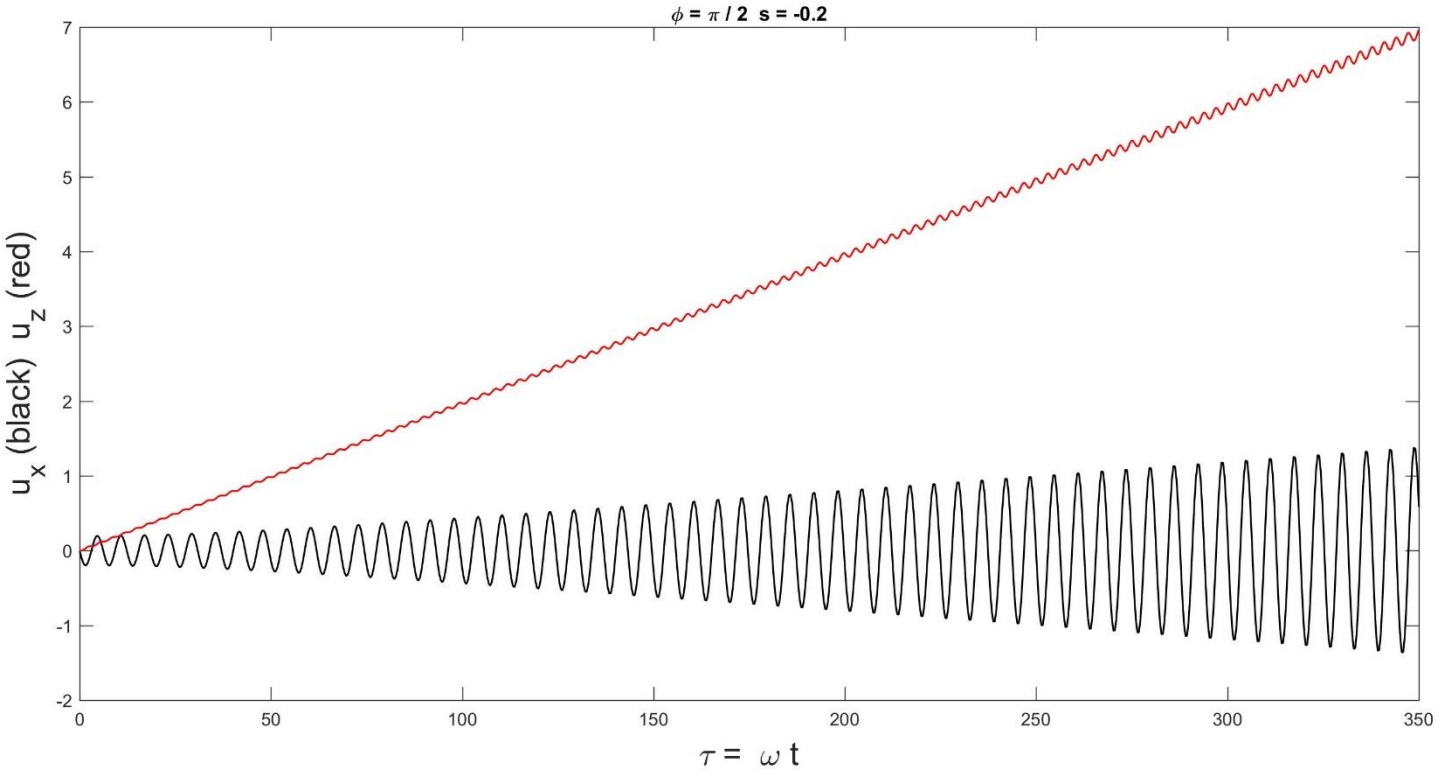
$\phi = 0 \quad s = -0.2$



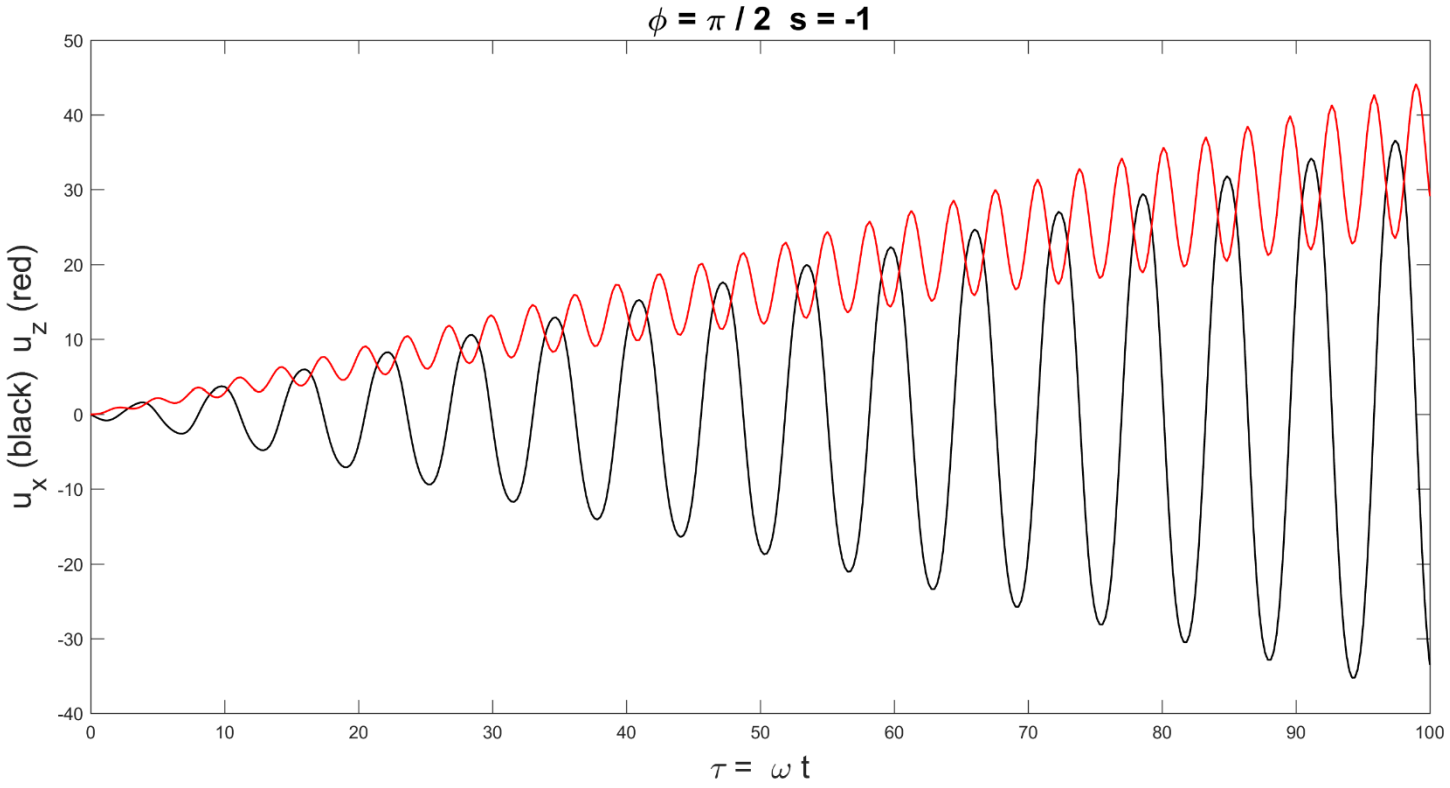
$\phi = 0 \quad s = -2$



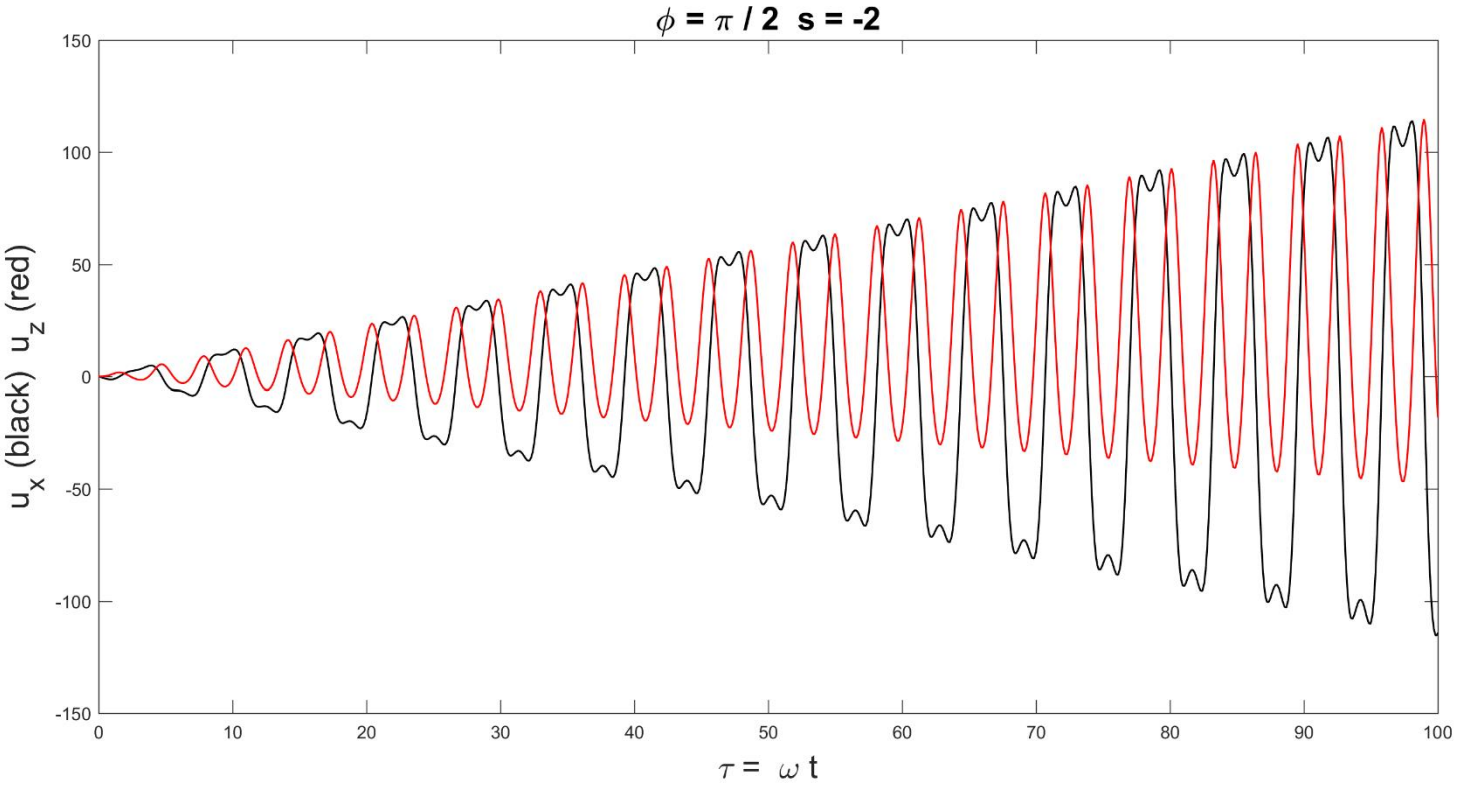
$\phi = \pi / 2 \quad s = -0.2$



$\phi = \pi / 2 \quad s = -1$



$\phi = \pi / 2 \quad s = -2$



Equations of motion – ions and electrons

- A space-charge is formed to prevent axial current.

Equations of motion – ions and electrons

$$\vec{E} = \hat{x} E_0 \cos(\omega t) + \hat{z} E_z \qquad \vec{B} = \hat{y} B_0 \cos(\omega t - \phi).$$

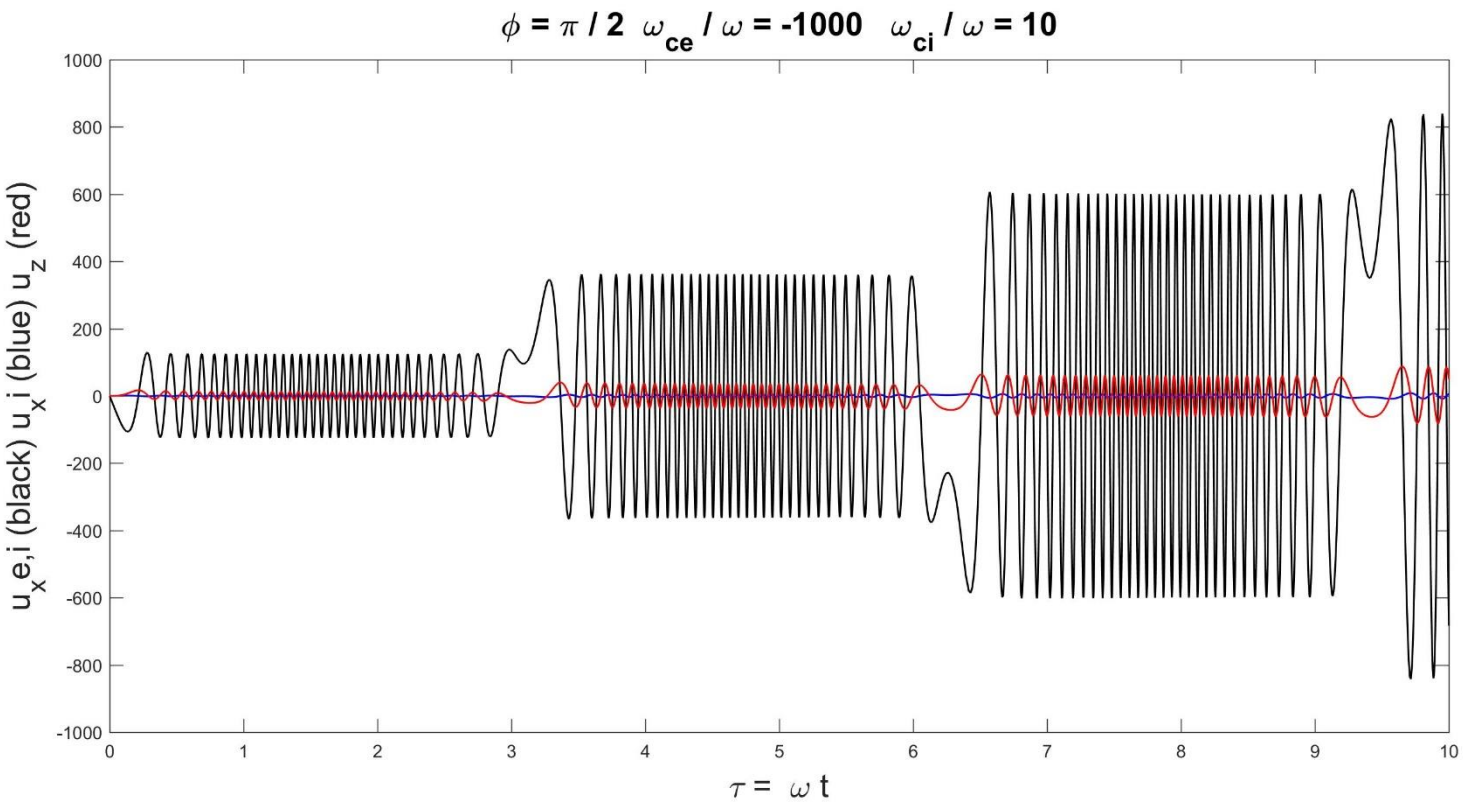
$$\frac{du_{xe,i}}{d\tau} = s_{e,i}\left[\cos(\tau) - u_z \cos(\tau - \phi)\right],$$

$$\frac{du_z}{d\tau} = \frac{s_i s_e}{s_i - s_e}\left(u_{xe} - u_{xi}\right)\cos(\tau - \phi).$$

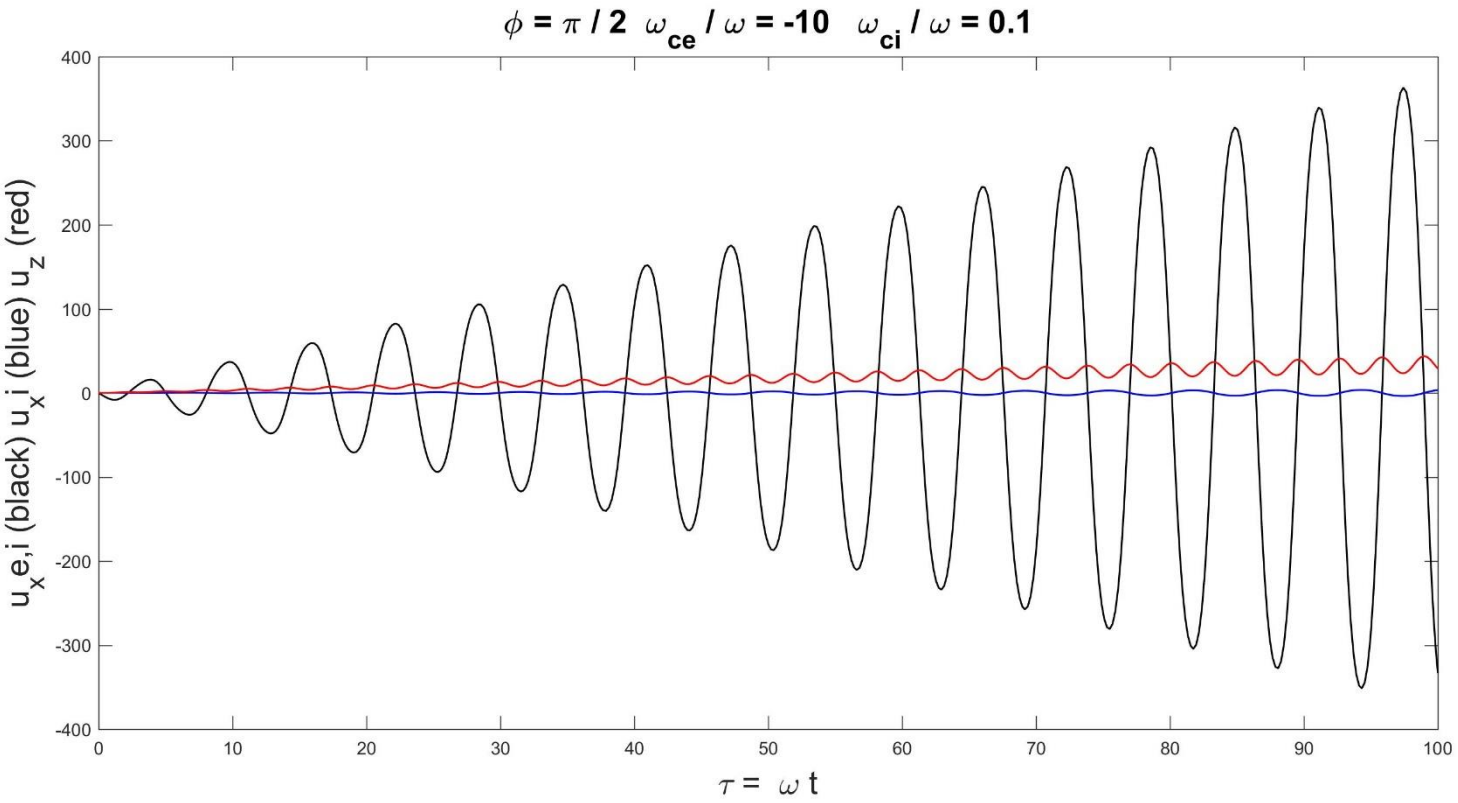
$$E_z = E_0\left(\frac{s_e u_{xe} - s_i u_{xe}}{s_i - s_e}\right)\cos(\tau - \phi)$$

$$\vec{u} \equiv \frac{\vec{v}}{E_0 / B_0} \qquad \tau \equiv \omega t \qquad s \equiv \frac{eB_0}{m\omega} = \frac{\omega_c}{\omega}.$$

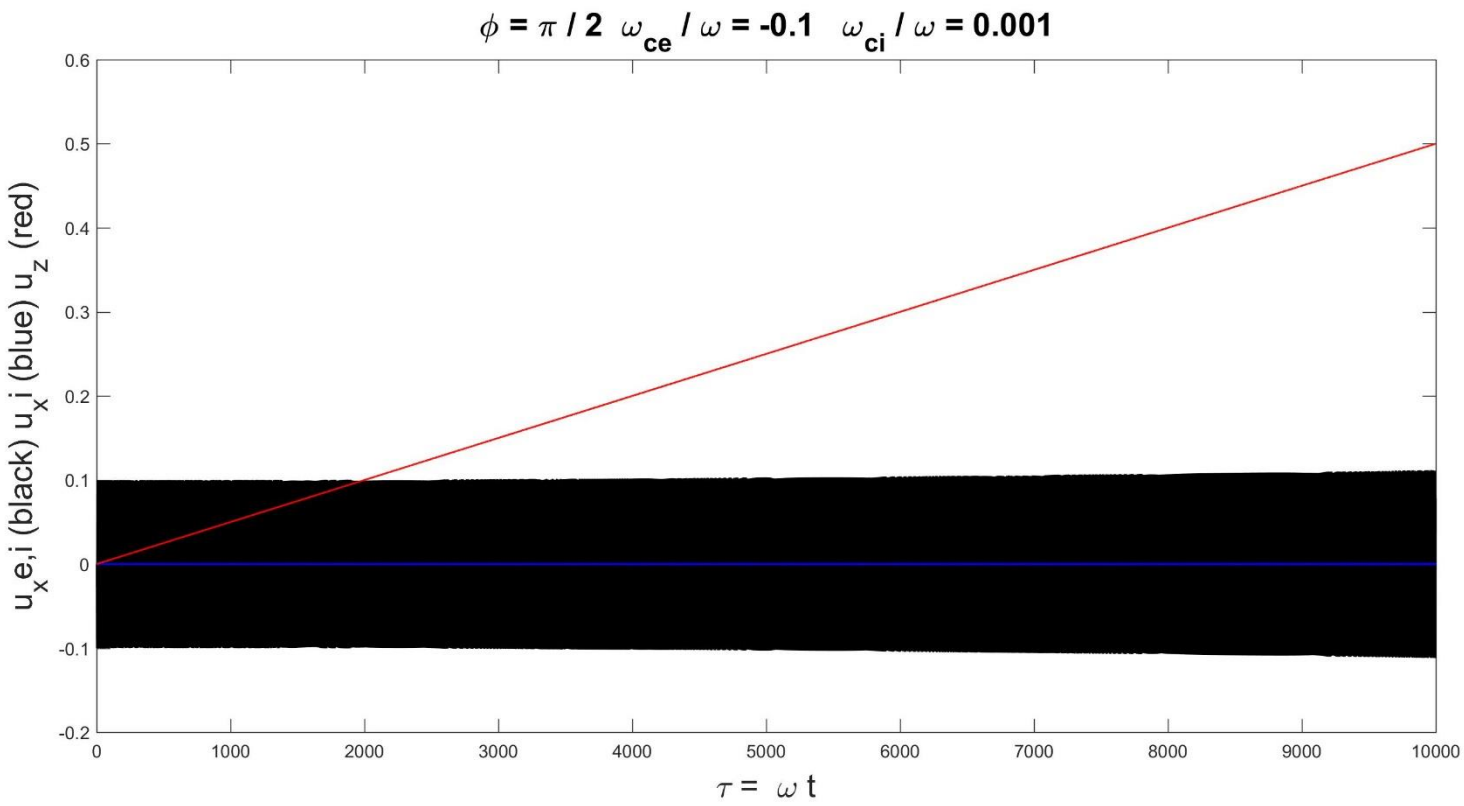
$\phi = \pi / 2$


$\phi = \pi / 2$ $\omega_{ce} / \omega = -1000$ $\omega_{ci} / \omega = 10$
$u_x e,i$ (black) $u_x i$ (blue) u_z (red)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
0
1
2
3
4
5
6
7
8
9
10
$\tau = \omega t$

$\phi = \pi / 2$


$\phi = \pi / 2$ $\omega_{ce} / \omega = -10$ $\omega_{ci} / \omega = 0.1$
u_xe,i (black) u_xi (blue) u_z (red)
$\tau = \omega t$
400
300
200
100
0
-100
-200
-300
-400
0
10
20
30
40
50
60
70
80
90
100

$\phi = \pi / 2$


$\phi = \pi / 2$ $\omega_{ce} / \omega = -0.1$ $\omega_{ci} / \omega = 0.001$
u_xe,i (black) u_xi (blue) u_z (red)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
$\tau = \omega$ t

Summary

- Oscillating electric and magnetic fields can accelerate particles for the proper phase difference between them.
- For a neutral plasma of the same mass particles (electron-positron plasma), such fields accelerate all plasma.
- In an electron-ion plasma a space-charge electric field is generated that accelerates plasma for a high frequency.
- A spatial dependence of the fields has to be added.