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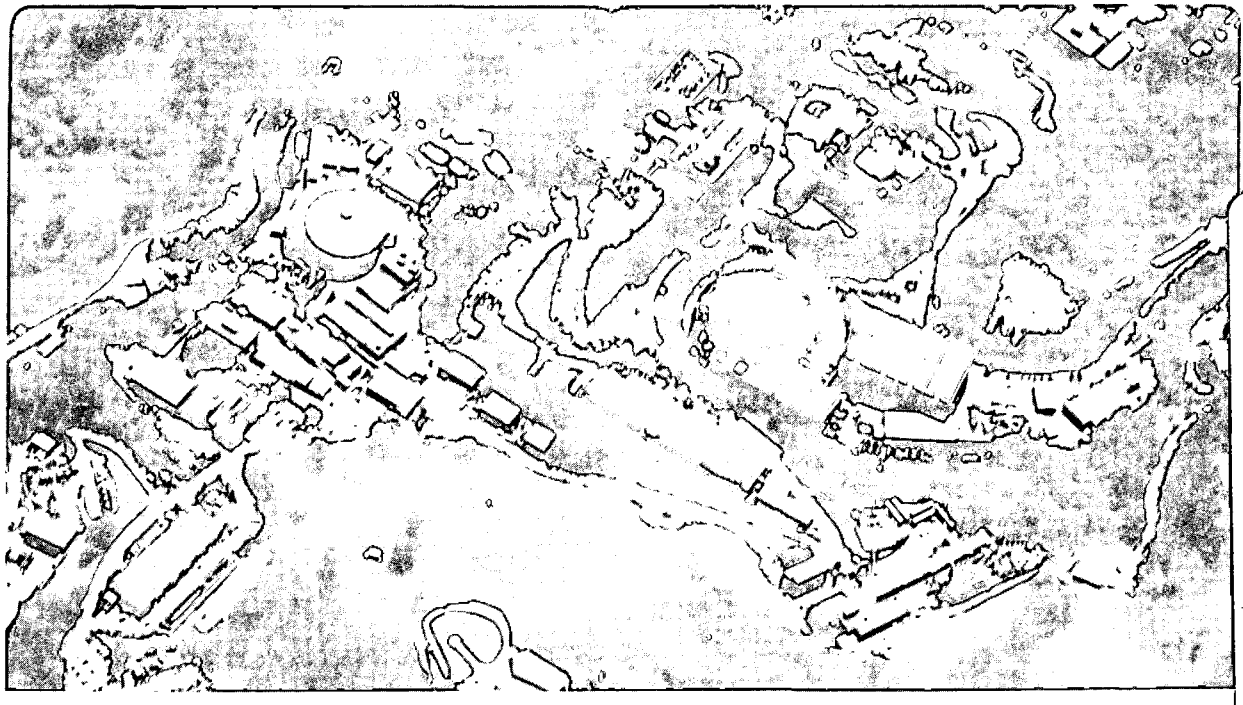

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Towards the Construction of a High-Intensity Source of Totally Polarized Electrons*

M. Zolotorev

Lawrence Berkeley Laboratory

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ABSTRACT

A scheme for construction of an intense source of totally polarized electrons is suggested with the parameters: 15 A current, 2 ns time duration and 180 Hz repetition rate. Such a polarized gun could be used at the SLAC Linear Collider.

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1. INTRODUCTION

One of the main problems to be studied at the SLC is the interaction of polarized electrons with positrons [1]. For this purpose, a source of electrons is now under construction. The maximum degree of polarization in this source is fundamentally restricted to be 50%. In this note a new type of source is suggested which gives the possibility to obtain 100% polarization. As a result, new experiments in the investigation of electroweak processes are available.

In contrast to the present solid state source, we suggest using an atomic beam. There are two main problems in the construction of intense sources of this type. The first is to obtain a plasma with totally polarized electrons. The second is to extract these electrons from the plasma. These two problems are discussed in this note.

2. PREPARATION OF POLARIZED ELECTRONS

As one possible example, consider sodium (see figure 1). The ground state of sodium is $3S_{1/2}$, with nuclear spin I=3/2. Due to the hyperfine interaction, the ground state is split into sub-levels, with total angular momentum F=1 or 2 ($\mathbf{F} = \mathbf{I} + \mathbf{J}$, where $\mathbf{J}$ is the full angular momentum of the valence electron). The spacing between these two sub-levels is 1.78 GHz. In what follows we are interested in resonance-induced transitions from the ground state to the $3P_{3/2}$ level (the D2 sodium yellow line). This upper level is also split by the hyperfine interaction, with F = 3, 2, 1, or 0. The spacing between these sublevels is much smaller than for the ground state, and is about 60 MHz.

The width of the excited $3P_{3/2}$ state is known to be 10 MHz. When the atoms are illuminated with laser light in resonance with this transition, stimulated emission increases this width . With a power density of 7 mW/cm^2, the stimulated emission rate is equal to the spontaneous emission rate. When the laser power is increased far beyond this level,

stimulated emission dominates and the width becomes the Rabi frequency $\omega_R = 2dE / h$, where d=transition dipole moment, E=amplitude of electric field of the light. Therefore, if we use a laser with power density greater than 300 W/cm^2, the linewidth becomes greater than the distance between the ground hyperfine sublevels. In this case, the hyperfine interaction can be neglected.

The transition scheme proposed here is shown in figure 2. Under the influence of circularly polarized light (for example, right), the allowed transitions are:

$3\ S_{1/2};\ m=-1/2 \leftrightarrow 3\ P_{3/2}\ m=+1/2$

$3\ S_{1/2};\ m=+1/2 \leftrightarrow 3\ P_{3/2};\ m=+3/2$

Additionally, we need to consider the effect of spontaneous emission from the excited $3P_{3/2}$ states:

$3\ P_{3/2};\ m=+3/2 \rightarrow 3\ S_{1/2};\ m=+1/2$

$3\ P_{3/2};\ m = +1/2 \rightarrow 3\ S_{1/2};\ m=+1/2$

$\rightarrow 3\ S_{1/2};\ m=-1/2$

It is clear that if the interaction of the atoms with the laser light lasts longer than several times the *spontaneous* decay time, the system will be optically pumped with half the atoms in the $3\ P_{3/2};\ m=+3/2$ state, half in the $3\ S_{1/2}\ m=+1/2$ state, and all other states empty. Since the $3\ P_{3/2};\ m=+3/2$ state has the maximum total angular momentum as well as the maximum projection of angular momentum, the electron spin must be fully polarized.

If we now subject the sodium atoms to strong right-polarized laser light with photon energy larger than the ionization energy for the $3P_{3/2}$ level (3.0 eV), but less than

for the ground state (5.2 eV), then the atoms will be ionized to the continuum $D_{5/2}$; m=+5/2 state. Again, since this state has maximum value of the total angular momentum, as well as its projection, the continuum electron is fully spin polarized.

There currently exist flashlamp pumped pulsed dye lasers suitable for the first stage of this process. If we assume that the cross-section for photoionization from $3P_{3/2} \rightarrow D_{5/2}$ is typical for photoionization (of the order 10^{-17} to 10^{-18} cm^2), then existing excimer laser technology can provide enough intensity to produce 10^{11} to 10^{12} polarized electrons.

3. EXTRACTION OF THE POLARIZED ELECTRON BEAM

To produce an electron beam, we suggest the scheme shown in figure 3. After the ionization process, we apply a short (~1 nsec) ~2 kV electric pulse across electrodes 2 and 4, such that $\int E\, dt$ corresponds to about 500 eV kinetic energy for the electrons. Since the pulse duration is short, practically none of the electrons have time to travel out of the electric field during the pulse -- thus, all the electrons receive the same momentum kick.

As the head of the electron bunch enters the region between electrodes 4 and 5, they experience a large accelerating and focusing field. If the geometry of the existing thermionic source gun is used for the focusing electrode and anode, then we already know that this part of the system can deliver a space-charge limited current of 15 A [2].

As the tail of the electron bunch begins to move away from the underlying ions, space charge quickly arises. If some efforts are not taken to compensate this, the electron bunch will be destroyed. This space charge can be compensated by injecting new (unpolarized) electrons in behind the tail from either a thermal- or photo-cathode (electrode 1 in figure 3). If we carefully adjust the density and velocity of this second electron current, we can overcome this difficulty in a "soft" and continuous way. Then, the entire space-charge load is taken up by the thermal- or photo-cathode.

After the polarized electrons leave the region between electrodes 2 and 4, we must stop the unpolarized electrons that follow them. We can do this simply by applying another

short voltage pulse across electrodes 2 and 4, identical to the first pulse but of opposite polarity.

For operation at the SLC, a polarized electron gun must produce 2 electron bunches (the second bunch used for positron production). To produce this second bunch, we simply wait the nominal time (62 nsec), and then repeat the extraction process just described. Atomic recombination can be completely neglected, so the unpolarized electrons that were used to cancel the space charge for the first pulse can be extracted as the second pulse. A new bunch of (unpolarized) electrons again compensates the space charge of the plasma from the thermal- or photo-cathode.

In the time between firing cycles at the SLC (approximately 5 milliseconds), there is more than enough time to replace the plasma with fresh sodium atoms to repeat the process.

4. CONCLUSIONS

The scheme presented here should be able to produce fully polarized electrons for use at the SLC. Methods have been proposed to overcome the problems of 100% polarization production, space charge in the plasma, and production of the positron-producing second electron bunch. Furthermore, with appropriate modification, this approach could be used in other applications requiring pulsed high-current polarized electron sources.

I am grateful to E. Commins for many fruitful discussions of this scheme, and to M. Kowitt for help in this work.

REFERENCES

1. Proceedings of the SLC workshop on experimental use of the SLAC linear collider, SLAC-REPORT-247, March 1982.

2. R. F.Koontz, SLAC-PUB-2824, October 1981.

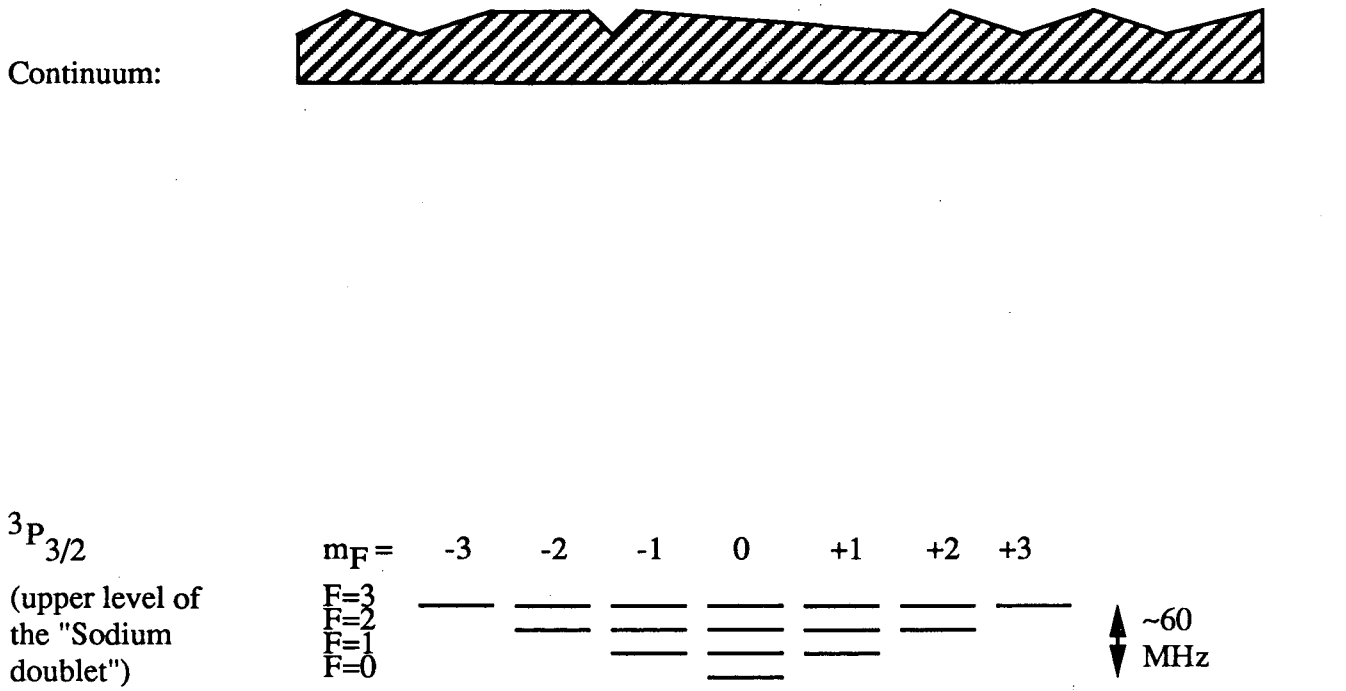

Continuum:
$^3P_{3/2}$
(upper level of the "Sodium doublet")
m_F = -3 -2 -1 0 +1 +2 +3
F=3
F=2
F=1
F=0
~60 MHz
ground state
$^3S_{1/2}$, I=3/2
F=2
F=1
m_F = -2 -1 0 +1 +2
~ 1.8 GHz

Figure 1

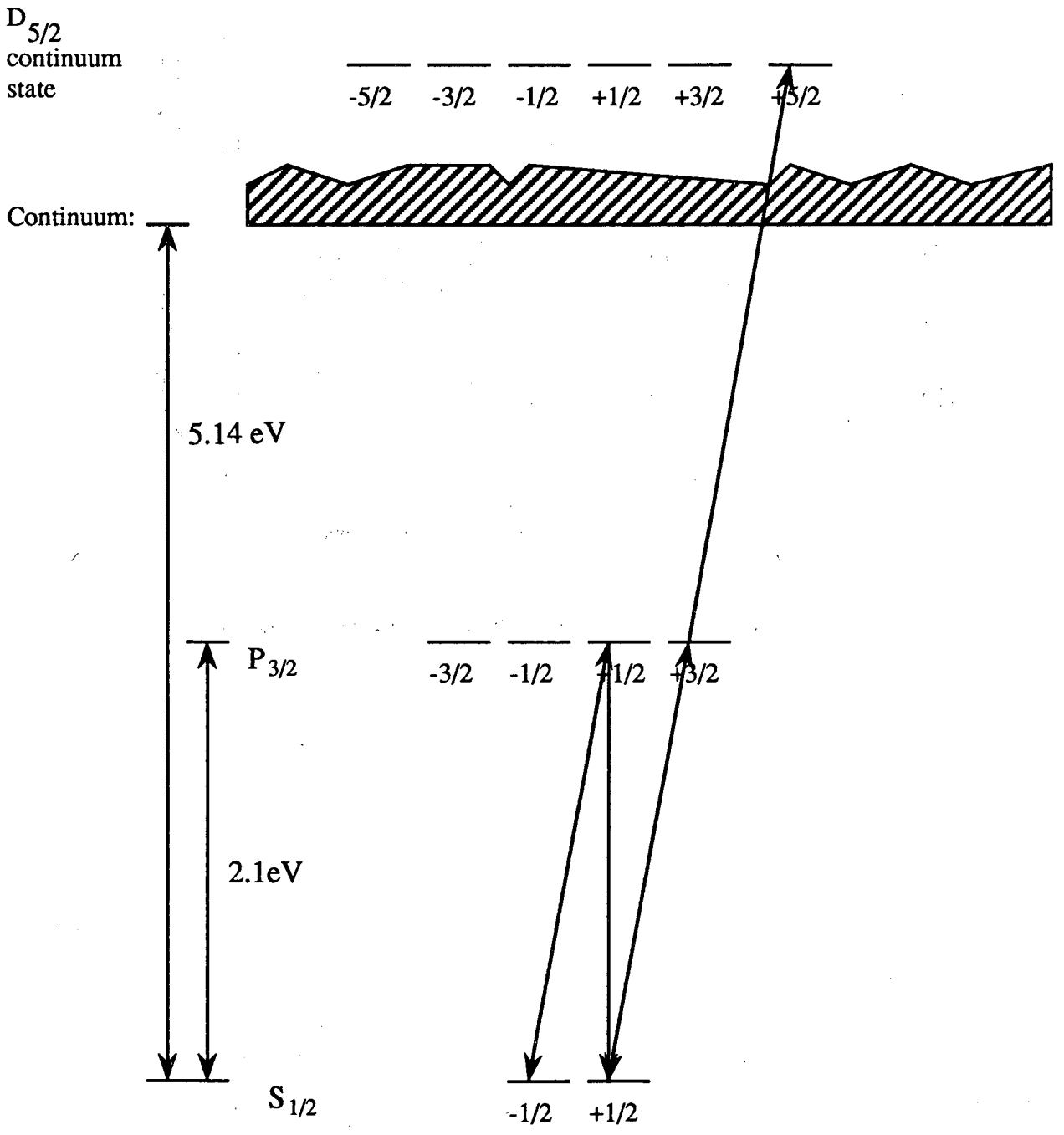
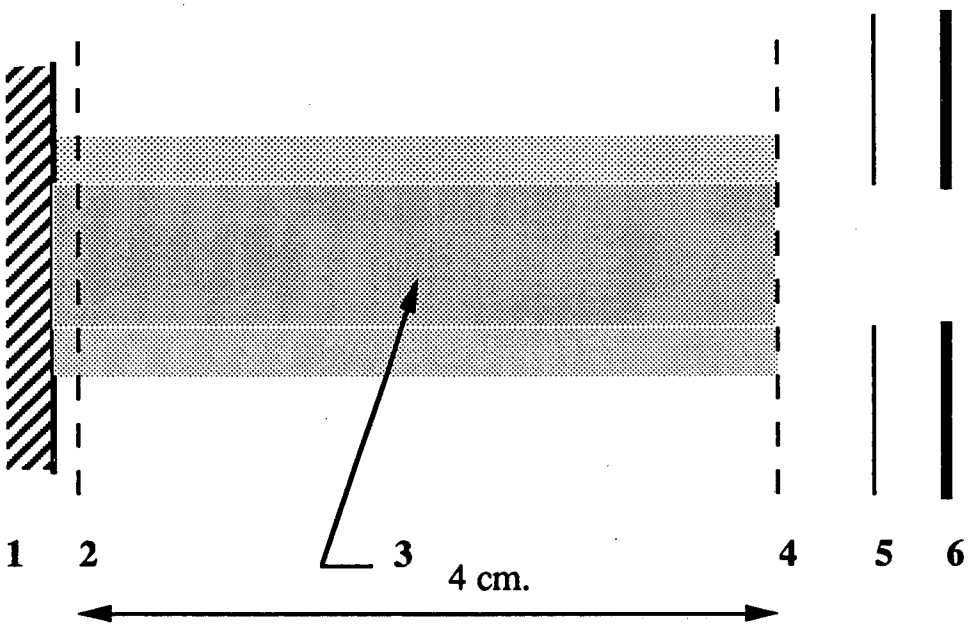

$D_{5/2}$
continuum
state
-5/2
-3/2
-1/2
+1/2
+3/2
+5/2
Continuum:
5.14 eV
$P_{3/2}$
-3/2
-1/2
+1/2
+3/2
2.1eV
$S_{1/2}$
-1/2
+1/2

Figure 2



1 - thermal- or photo-cathode; 2 - cathode grid; 3- polarized plasma;
4 - second grid; 5 - focusing electrode; 6 - anode

Figure 3

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