$P_{ms} = 1.04$ ms. If their mass is $1.4\,M_{\odot}$, then faster pulsars, with periods as short as 1 ms, should also be seen.

The general relativistic effects are expected to be important for the millisecond pulsar. If one retains terms of order c^2, one can write the post-newtonian corrections[8]:

$$\frac{\Omega^2}{\pi G\rho} = \frac{\Omega_N^2}{\pi G\rho} + \frac{R_s}{a_1} f(e).$$

Here Ω_N is the newtonian angular velocity, $R_s = 2GM/c^2$ is the Schwarzschild radius of the neutron star and $a_1 = a_2$ the longer axis. $f(e)$ is an involved function of the eccentricity and is tabulated by Chandrasekhar[8].

Thus if the post-newtonian effects are included, then for a given $\Omega^2/\pi G\rho$ the eccentricity is lower than the classical value (figure 1). The point of bifurcation and the point of maximum Ω^2 still occur at the same value of e, but now correspond to a higher Ω.

For a $0.7\,M_{\odot}$ neutron star, the point of bifurcation occurs at $\Omega^2/\pi G\rho = 0.4$, whereas for a $1.4\,M_{\odot}$ neutron star the corresponding value is 0.43. Thus the post-newtonian effects are about 10% of the classical values.

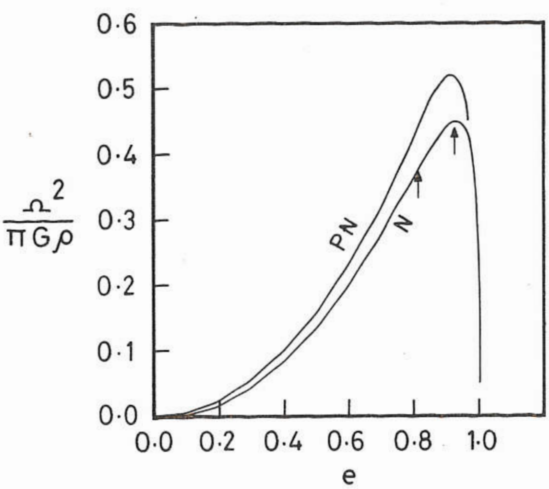

Figure 1. The square of the angular velocity (in the unit $\pi G\rho$) along the Maclaurin sequence as a function of the eccentricity. The classical (N) curve and the post-newtonian curve for mass $= 1.4\,M_{\odot}$ (PN) are shown; for the latter only values upto $e = 0.98$ are plotted. Curve for $M = 0.7\,M_{\odot}$ is very close to the $1.4\,M_{\odot}$ curve and is omitted. The point of bifurcation ($e = 0.81267$) and the point of maximum Ω ($e = 0.93$) are the same for the newtonian as well as the post-newtonian case and are marked.

In the post-newtonian approximation, the 1.56 ms pulsar has an eccentricity $e = 0.73$ ($M = 0.7\,M_{\odot}$) or $e = 0.5$ ($M = 1.4\,M_{\odot}$). The point of bifurcation now corresponds to $P_{ms} = 1.5$ for a $0.7\,M_{\odot}$ neutron star. With post-newtonian effects included, a $1.4\,M_{\odot}$ neutron star will have a period of 0.98 ms at the point of bifurcation, which is the shortest it can have.

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PRODUCTION OF H^- ION BEAM USING DUOPLASMATRON SOURCE

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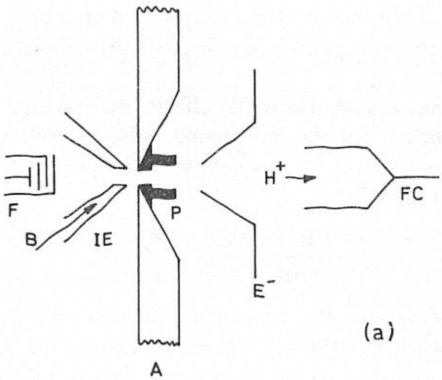
THE efficiency of direct extraction of H^- ion from a duoplasmatron ion source by on-axis and off-axis extraction technique has been found to be very small[1, 2]. Recently a concept of ion source, in which negative surface ionization (NSI) of hydrogen can be used as a tool to produce H^- ion beam, has been proposed by several authors[3]. Measurement[4] of large conversion efficiency (up to 40%) of H^+ into H^- by NSI technique has given the prospect of utilising the duoplasmatron as an efficient negative ion source. We have started an experiment, the aim of which is to use a duoplasmatron to produce H^- ion beam efficiently, by the NSI technique. Since the NSI technique would need to impinging H^+ ion to be of lower energy, the duoplasmatron should be operated at its low-extraction voltage mode. But it is known that the usual extraction voltage for duoplasmatron type source is several tens of kV[5]. It is, therefore, desirable that the plasma of duoplasmatron should be given expansion and the ion should be extracted at lower extraction voltage (< 10 kV). In the usual plasma expansion technique, the operation of duoplasmatron at high arc current needs the dimension of the expansion cylinder to be quite large, which causes greater loss of ions to the walls[6]. This wall loss can be reduced by using prefocussing electrode (PFE)[7] which however suffers from the drawback of drainage of large electron current from the expanding plasma, causing unnecessary power drainage from the high voltage power supply. In our experiment we have used smaller size expansion cylinder fitted with anode and regulated the arc current to a desired value so that the plasma takes proper boundary inside the plasma expansion cylinder and at lower extraction voltage (< 10 kV) extraction is possible, making the extractor loss almost zero.

Figure 1(a) shows our experimental arrangement for H^+ ion extraction from duoplasmatron source. The plasma expansion cylinder P of dimensions 6 mm ID, 8 mm OD and 6 mm length was fitted with the anode A having 3 mm emission aperture. The H^+ ion extractor E^- having 6 mm hole was about 6 mm away from the P and was biased to suitable negative voltages for H^+ ion extraction. The extracted H^+ ion current was measured in a biased Faraday cage FC. Sample data of extracted H^+ ion current at two different arc currents (600 mA, 800 mA) are shown in table 1. In figure 2 are drawn the extraction characteristic curves using the values shown in table 1. It can be seen in these curves that at comparatively lower arc currents (600 mA, 800 mA) and with smaller size of P, almost full transmission of extracted H^+ ion current can be achieved with the extractor loss becoming negligibly small at an extractor potential of < 10 kV. In this region of operation both the arc current and the extracted beam current were very stable. Figure 1(b) describes the modifications done for conversion of H^+ into H^- by incorporating (i) a cylindrical brass tube whose inside surface was coated with thick layer (3 mg/cm^2) of cesium CS, (ii) a negative ion extraction electrode E^+, having 6 mm hole and 6 mm away from

Table 1. *Sample data of extracted H^+ ion current at two different arc currents*

Arc current (mA)	Extractor potential (−kV)	Extractor current (mA)	Extracted current (mA)
600	3	2	1
	5.5	1	1.7
	7.5	~0	2.2
	9.5	~0	2.6
800	3	2	0.6
	5.5	1.5	1.8
	7.5	0.5	2.6
	8	0.4	2.8
	8.5	0.2	3.4
	9	~0	3.6
	9.5	~0	3.6
	10	~0	3.6



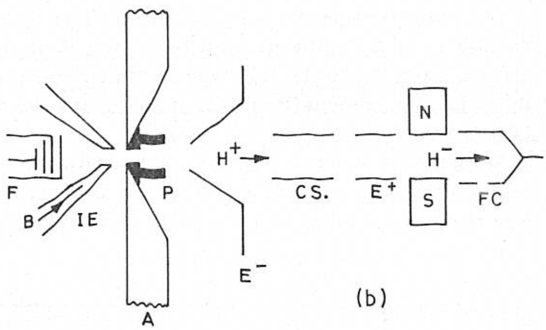


Figure 1(a). Schematic arrangement of duoplasmatron with usual extraction system. Filament F, Intermediate electrode IE, Magnetic field B, Anode A at ground potential constitute the duoplasmatron source. Plasma expansion cylinder P at anode potential, H^+ ion extractor (−kV) E^-, Faraday cage FC, constitute the usual extraction system of the duoplasmatron source. **1(b).** Scheme of production of H^- ion beam using H^+ ion extracted from the duoplasmatron source. Cesium-coated surface CS, H^- ion extractor (+kV)E^+, Transverse magnetic field NS, Farady cage FC constitute the H^- ion extraction system.

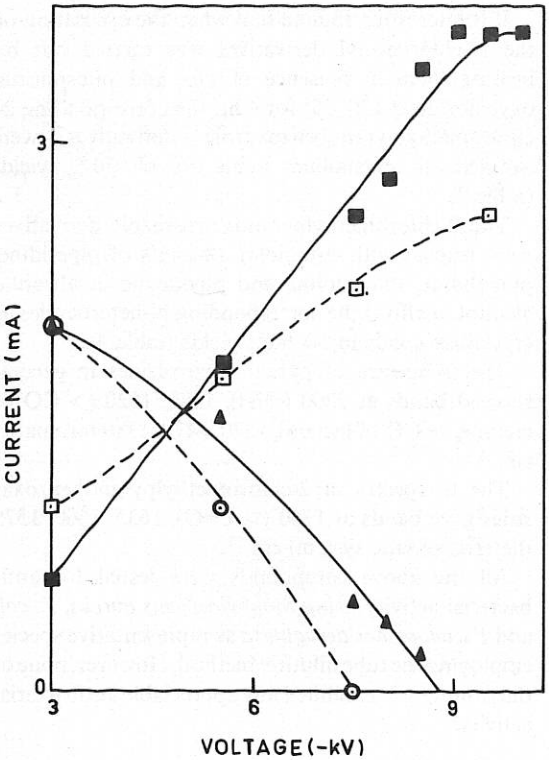


Figure 2. Extraction characteristic (current *vs* voltage) at two different arc currents. For arc current 600 mA, extracted current *vs* extractor voltage is denoted by open square and extractor current *vs* extractor voltage is denoted by open circle. For arc current 800 mA, the extracted and extractor currents are, respectively, indicated by solid square and solid triangle.

CS and biased positively, and (iii) a small transverse magnetic field NS of about 400 Gauss for excluding electrons from the extracted H^- ions, in the extraction system of duoplasmatron source. The extractor E^- was biased at -3 kV for which extracted H^+ ion current was 1 mA. This was then allowed to interact within the inside surface of CS. H^- ions formed in the CS were extracted by E^+ biased at $+2$ kV and measured by FC properly biased. For the incident 1 mA H^+ current at -3 kV, we found H^- current of nearly 40 μA, showing a percentage yield of about 4%.

A yield of 4% H^- ion beam is definitely an improvement on previous attempts by various workers to extract H^- ion beam directly from duoplasmatron. For example, in the experiment of Abroyan *et al*[8] it can be seen that the yield of H^- ion beam is only about 0.25%. Further it is expected that this yield of 4% H^- found by us can be improved to a much higher figure, if the energy of incident H^+ ion beam is suitably reduced, such that the interaction cross-section is higher. van Wunnik *et al*[4] have found that, for grazing incidence, the yield of H^- ion increases from 5% to 35% (approximately) for a decrease of energy from 2000 ev to 100 ev (approximately). We are now engaged in a detailed study of production of H^- ion beam from the duoplasmatron, by NSI technique.

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