CURRENT SCIENCE

Volume 66 Number 1 10 January 1994

NEWS

Nobel Prize for Physics

The Nobel Prize for Physics for the year 1993 has been awarded to Joseph H. Taylor and Russell A. Hulse for the discovery of the binary pulsar PSR 1913 + 16. As a part of a systematic survey of the sky for pulsars with the 1000 ft diameter Arecibo Telescope in Puerto Rico, this object was found in July 1974. It had a characteristic very unusual for pulsars known till then: its 59 ms period was changing by up to 80 µs from day to day. Soon it was realized that this variation in its apparent period is due to the Doppler effect associated with its orbital motion in a binary system. This was the first pulsar to be discovered which had a binary companion[1].

Since the discovery, prolonged observations by Taylor and his colleagues have led to very precise determinations of the orbital characteristics of the PSR 1913 + 16 system, and most interestingly, have revealed a number of non-Newtonian gravitational effects, making this system one of the best laboratories to study theories of gravitation, in particular the general theory of relativity.

The observations required to study this object are in principle quite simple, and are popularly known as pulse timing. It involves accurate measurement of the arrival time of each pulse on the earth, using the best clock available. Since PSR 1913 + 16 is relatively weak, Taylor and his colleagues usually average 5 minutes of data and time-tag the resulting profiles. In the absence of any relative motion between the earth and the pulsar, the pulses would arrive on the earth exactly equispaced in time. But in reality the observed pulse arrival times are not equispaced, as a result of two effects. One is the motion of the observatory due to the spin and the orbital motion of the earth, and the other is the motion of the pulsar in its binary orbit. The former, being of known magnitude, can be corrected for to yield precise measurement of the orbital motion of the pulsar.

The orbit of the pulsar is characterized by six parameters: the orbital period P_b, the semi-major axis a, the inclination i of the orbit normal with respect to the line-of-sight, the eccentricity e, the longitude of the periastron ω and the time of periastron passage T_0. The quantities a and i are usually combined into one measurable quantity $x = a \sin i$, the projected semi-major axis. Taylor and his colleagues have now determined all these five quantities with the significance of seven or more significant digits[2], as quoted in Table 1.

The orbital period of 7.75 hours puts this binary among the ones with shortest periods. The small size of the orbit precludes the possibility that the companion of the pulsar is a normal star. Only a compact star (white dwarf, neutron star or a black hole) or a helium star could fit into the orbit[3], but with a white dwarf or a helium star companion it would be very hard to explain the high eccentricity of the orbit on evolutionary grounds (tidal interactions with the progenitor of either would circularize the orbit). It was thus fairly clear that the companion must be either a neutron star or a black hole. In either case the size of both the components of the binary system would be much smaller than the orbital separation, thus tidal effects would be negligible—they would essentially behave as two point masses in orbit. The pulsar itself had somewhat peculiar characteristics: its spin period was among the shortest known, and its magnetic field strength was two orders of magnitude lower than most other pulsars. This peculiar combination of short period and low magnetic field fitted into the evolutionary picture, if the pulsar was the first-born compact star in the system and had been spun-up by accreting matter from the progenitor of the present companion[4]. This necessitated the eccentricity of the orbit to be induced by a second supernova explosion in the system: again arguing that the companion must either be a neutron star or a black hole.

The precise measurement of the orbital parameters has enabled Taylor and his colleagues to monitor the *change* in them over the years. The first to be measured was the rate of change of the longitude of the periastron, namely, $\dot{\omega}$: the rate of precession of the orbit. As the components are essentially point masses, this effect is wholly general-relativistic. The measured precession rate is a whopping 4.22

Table 1. Orbital parameters of PSR 1913 + 16 system

Orbital period P_b (s)	27906.9807807(9)
Eccentricity e	0.6171309(6)
Projected semimajor axis x (light-s)	2.341759(3)
Time of periastron T_0 (Julian Day)	2446443.99588321(5)
Longitude of periastron ω (deg)	226.57531(9)
Advance of periastron $\dot{\omega}$ (deg/yr)	4.226628(18)
Time dilation γ (ms)	4.294(3)
Orbital period derivative $\dot{P}_b$	$-2.425(10) \times 10^{-12}$

Figures in parentheses represent uncertainty in the last digit (Data from Taylor *et al.*[2])

deg/yr (see Table 1), more than 35000 times larger than the precession rate of the orbit of the planet Mercury. As this change of the longitude of the periastron gradually allowed us to see the orbit in different orientations, the measurement of a second relativistic parameter γ which combines the time dilation effects due to transverse doppler shift and gravitational redshift, became possible. With these two measurements the orbit could be completely solved for, and the masses of both the components determined. The mass of the pulsar turned out to be 1.442 ± 0.003 solar masses[5], remarkably close to the Chandrasekhar limit, at which the degenerate core of a massive star is expected to collapse and form a neutron star. This stands as the most accurate measurement of the mass of a neutron star till today. The mass of the companion, too, is very close to this, 1.386 ± 0.003 solar masses, which strongly suggests that even the companion is a neutron star. This companion neutron star is not directly visible to us either because it is not functioning as a pulsar or if it is, its beam of radiation is not directed towards the earth.

The third, and perhaps the most important parameter to be measured for the PSR 1913 ± 16 system was the rate of change of the orbital period, $\dot{P}_b$. The orbital period is shortening with time, which means that the components are coming closer to each other. The binary is thus losing energy, and the only reason for this could be the emission of gravitational radiation. Thus this was the first, though indirect, proof of the existence of gravitational radiation. In addition, it served as an important verification of the Einstein's theory of gravitation. With the latest measurements (Table 1), the ratio of the observed $\dot{P}_b$ to that predicted by general relativity stands at 1.0023 ± 0.0047—an impressive agreement[2]!

These observations have of late also led to an important theoretical activity of parametrizing all existing theories of gravitation in terms of parameters that can be fitted to the timing data on the binary pulsar[2, 6–8]. The predictions from general relativity still fit very well the data on this binary pulsar, and two others that were discovered rather recently. The data already strongly constrain most other theories of gravity. In time, binary pulsar systems will provide even tighter constraints on theories of gravitation, and judging by the present trend, general relativity is well on its way to emerge the final winner.

---

1. Hulse, R. A. and Taylor, J. H., *Astrophys. J.*, 1975, **195**, L51.
2. Taylor, J. H., Wolszczan, A., Damour, T. and Weisberg, J. M., *Nature*, 1992, **355**, 132.
3. Smarr, L. L. and Blandford, R. D., *Astrophys. J.*, 1976, **207**, 574
4. Srinivasan, G. and van den Heuvel, E. P. J., *Astron. Astrophys.*, 1982, **108**, 143.
5. Taylor, J. H. and Weisberg, J. M., *Astrophys. J.*, 1989, **345**, 434.
6. Damour, T. and Deruelle, N., *Ann. Inst H. Poincaré (Phys. Théor.)*, 1985, **43**, 107.
7. Damour, T. and Deruelle, N., *Ann. Inst H. Poincaré (Phys. Théor.)*, 1986, **44**, 263.
8. Damour, T. and Taylor, J. H., *Phys. Rev.*, 1992, **D45**, 1840.

Dipankar Bhattacharya, Raman Research Institute, Bangalore.

Nobel Prize for Chemistry

This year's Nobel prize for Chemistry was given to Michael Smith of the University of British Columbia, Vancouver, Canada and Kary B. Mullis of Cetus Corporation, USA (presently a freelance consultant) for developing methods for site-directed mutagenesis and amplification of DNA by polymerase chain reaction (PCR), respectively[1,2]. These methods have been so revolutionary that they have changed the way molecular biology is done today.

Site-directed mutagenesis allows one to introduce changes in the sequence of a given DNA. It has been instrumental in the study of the structure–function relationship(s) of the nucleic acids and the proteins (by mutating their genes). Further, it has allowed detailed understanding of nucleic acid protein interactions and various aspects of gene expression e.g. transcription, translation and processing of RNA and proteins etc. To perform site-directed mutagenesis one designs an oligodeoxyribonucleotide (oligo), complementary to the DNA to be mutagenized but with mismatches in regions where mutations are sought. Oligos containing deletions or insertions (with respect to the template DNA) can be used to perform deletion or insertion mutagenesis. DNA is usually cloned in bacteriophage vectors (e.g. M13) to obtain single-stranded DNA template. Various steps of mutagenesis are depicted in Figure 1. As shown, the procedure results

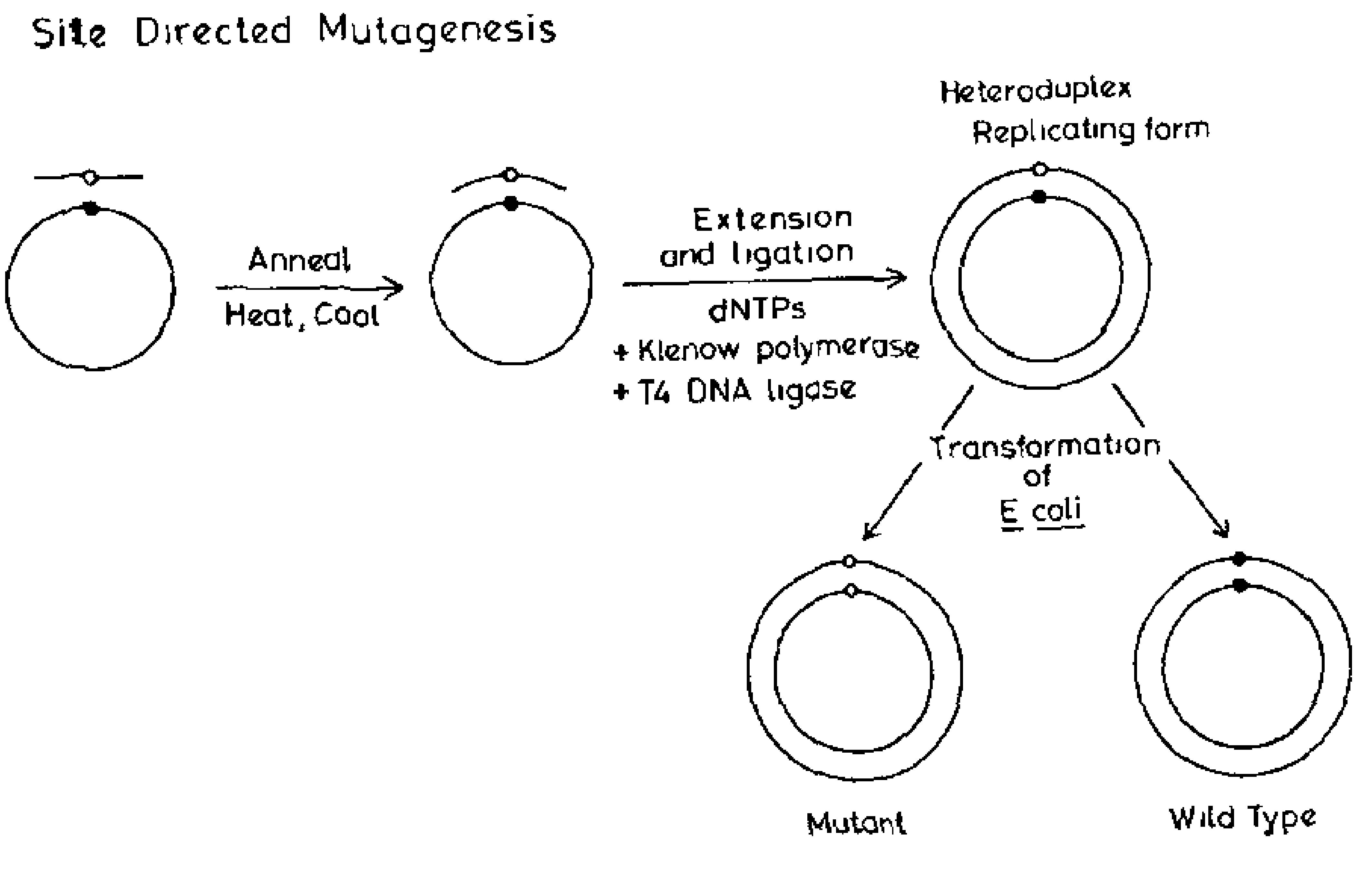

Figure 1. Site-directed mutagenesis. Single-stranded DNA from M13 recombinants is used as template. A complementary mutagenic oligo containing a mutation is used as primer. Second strand synthesis is carried out in the presence of dNTPs, Klenow polymerase and T4 DNA ligase. The heteroduplex replicating forms (RF) are used to transform *E. coli*. Hollow circles (o) and filled circles (•) represent mutated and wild type DNA sequence, respectively.