other that a celestial clock be used such as the steady progression of the Moon amongst the stars.

The two most promising methods—superior clocks and so-called lunar distances—were still far from accurate enough when the British government set up the Board of Longitude in 1714. Standard practice on long voyages was to run down lines of latitude into one's destination, a potentially catastrophic procedure if sailing to an island and unsure whether east or west of it. As late as 1741 Anson in the *Centurion* lost eighty men of scurvy in the twelve days he spent hunting for Juan Fernandez (of course not only were ships often misplaced, so, occasionally, were islands). The Board offered a results-related award—£20,000 for an accuracy of half a degree in longitude at the end of a six-week voyage to the West Indies, £10,000 for an accuracy of a degree. Sir Isaac Newton summarised the problems in making an accurate enough timekeeper—"the Motion of a Ship, the Variation of Heat and Cold, Wet and Dry, and the Difference of Gravity in different Latitudes". An accuracy of about two minutes would be needed at the end of the prescribed sea voyage for a half-degree accuracy, and clearly no pendulum clock would be up to that. Spring-driven clocks had been made as early as 1500 but by 1714 had never been compensated properly for temperature. Lunar distances might take the prize.

On the practical side one had to measure the angular distance between the moon and some prominent zodiacal star. This changes 13° in every 24 hours, so the invention in the 1720s of the reflecting octant with an angular accuracy of 1′ implied that if the lunar motion were perfectly tabulated, time by the Moon could be accurate to about two minutes once atmospheric refraction and geocentric parallax were allowed for. Two minutes of time is half a degree of longitude so the prize was in sight, at least if the tables could be perfected. It was to this that Tobias Mayer of Nuremberg and Göttingen most successfully devoted fifteen years from 1747.

Mayer was a cartographer and his interest in astronomical determinations of longitude came not from any nautical experience (he never even saw the sea) but from a desire to improve land surveying in Germany. He realised as he searched for higher accuracy that existing lunar data was unreliable and even that some of the stellar positions were unsatisfactory. Having read Euler on analysis and mechanics he ventured into the theory of the Moon's motion around a spheroidal Earth.

His first tables of the motions of the Moon in 1752 were criticised for discrepancies and for a certain inscrutability but by 1754 he had shown that the discrepancies were in contemporary star tables, and the usefulness of the tables for longitude determination was demonstrated. Euler now persuaded him to go for the prize money which he did in a Memorial to the Lords of the Admiralty beginning: "Having by indefatigable application and a great deal of trouble found out the longitude at sea . . . "

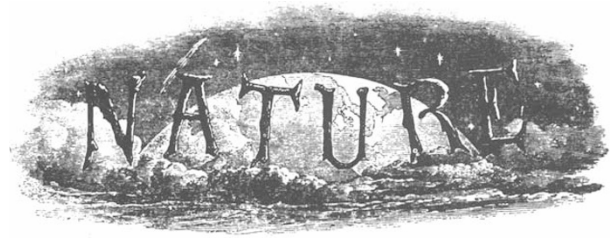
His work was well received in London, but the Board of Longitude delayed and Mayer died before a decision was made. Nevil Maskelyne, Astronomer Royal, used the tables with success on a voyage to St Helena in 1761 to observe a transit of Venus, and there was general agreement that Mayer's widow merited the £10,000 prize. The Board thought otherwise (they were probably somewhat embarrassed by their simultaneous encouragement of Harrison and his chronometers) and eventually awarded her only £3,000. This grudging acknowledgement did not inhibit the Commissioners of Longitude from using Tobias Mayer's tables to generate the first Nautical Almanac for 1767. But now the potentially more accurate chronometer, untied to problems of the Earth's rotation and the Moon's complex orbit, began to come to the fore.

John Harrison (1693–1776) stands out as a clockmaker head and shoulders above his contemporaries. He came to London in 1728 with two inventions which were to start him on a lifetime of battling with temperature fluctuations and poor lubrication—the 'gridiron' pendulum of brass and steel rods and the 'grasshopper' escapement which required no oiling. His first clock, H1, was tested so effectively on a voyage home from Lisbon in 1736 that Harrison, having estimated the position one and a half degrees west of the calculation by dead reckoning was proved right on landfall.

The money was not that easily won. The Board helped Harrison financially, but the Spanish wars and his own self criticism prevented a direct assault being made on the prize until 1761 by which time Harrison had built two other chronometers with which he was not totally satisfied, and now produced the watch H4, a mere five inches across. H4, surely the finest watch ever, was taken to Jamaica in an inconclusive trial, but in 1763 was tested again and showed an error of less than one tenth of a second per day. This should have brought Harrison his £20,000. The Board paid half but demanded that he secure his second £10,000 by showing that H4 could be made by others. Eventually George III exerted pressure and in 1773 Harrison received another £8,750.

Go to Greenwich to see Harrison's chronometers. They are displayed in a serene room almost inaccessible to the casual visitor like the Lady Chapel of some cathedral. The display is superb, as the big clanking clocks come on you one by one down the room. And then suddenly there is a small ticking watch, H4. The atmosphere is almost religious, and the visual surprise will live with you for a long time.

100 years ago



Colonel Gordon left Khartoum on March 21, and in his last letter from Fashoda, 10° N., he touches on some of the scenes on the banks of the river—the storks, which he was in the habit of seeing arrive on the Danube in April, laying back their heads between their wings and clapping their backs in joy at their return to their old nests on the houses, now wild and amongst the crocodiles 2,000 miles away from Turkey; the monkeys coming down to drink at the edge of the river, with their long tails, like swords, standing stiff up over their backs; the hippos and the crocodiles. Such scenes to a lover of nature, as Col. Gordon is, doubtless would serve to make up in some measure for the loss of civilised society and comforts.