F. LARSEN/CORBIS

Figure 1 | Genetics and the sun. Individuals with fair skin and red hair are more susceptible to melanoma than people who have darker complexions. Mitra *et al.*[1] show that this may be due not only to their greater sensitivity to sun exposure, but also to variants in their *MC1R* gene.

the redhead mice a white coat colour, it also reduced the incidence of melanoma among them. These results strongly indicate that the pheomelanin synthesis pathway plays an important part in melanoma development.

Why do redhead mice develop melanoma in the absence of UV light? It seems that redheads carrying RHC variants have a higher risk of melanoma because of intrinsic oxidative DNA damage, in addition to their poor protection from UV. Eumelanin is a strong antioxidant and reduces the accumulation of DNA damage by absorbing reactive oxygen species (ROS). Although pheomelanin may increase cancer risk by generating ROS in response to UV exposure[12], this pigment — or its chemical intermediates — can also generate ROS through a mechanism independent of UV radiation[13,14]. The present paper shows that ROS-mediated damage to both DNA and lipids accumulates more readily in the skins of Mc1r-mutant redhead mice than in Mc1r-mutant white mice, even without UV exposure. Moreover, any such exposure seems to exacerbate oxidative damage selectively in redhead mice[1].

Studies are under way to determine whether the increased melanoma risk in redheads is limited only to cancers driven by mutant *BRAF*, or whether it also applies to other melanoma oncogenes such as *NRAS*. In addition, it remains to be confirmed whether the risk of this cancer increases in individuals whose red hair is conferred by polymorphisms in other genes of the pigment pathway.

But perhaps the most pertinent question is what can be done, beyond sun protection, to decrease melanoma risk in red-haired, fair-skinned individuals? Destroying all melanin is not an option, because the skin would lack a natural sunshield — eumelanins. Besides, Mitra and co-workers' black mice were relatively well protected against melanoma even though they possessed both pheomelanin and eumelanin. It is conceivable that, in these animals, the abundant eumelanin scavenges pheomelanin-derived ROS. Therefore, it would be of great interest to determine whether topical compounds that induce eumelanin synthesis (such as forskolin), or oral intake of antioxidants, decrease melanoma risk in redheads. Moreover, red-haired individuals should undergo frequent dermatological skin checks, besides avoiding sun exposure. ■

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QUANTUM PHYSICS

Putting a spin on photon entanglement

Entanglement between a photon and a stationary particle is a key resource for quantum communication. The effect has now been observed for a photon and a single electron spin in a semiconductor nanostructure. SEE LETTERS P.421 & P.426

SOPHIA E. ECONOMOU

Quantum mechanics, the theory that explains the properties of matter through the motion of its microscopic constituents, is known for its peculiar and counter-intuitive concepts. These concepts are not only crucial to the structure of the theory, but also form the basis of many technologies, including lasers, the scanning tunnelling microscope and atomic clocks. In this issue, De Greve *et al.*[1] and Gao *et al.*[2] describe how they have independently demonstrated one such concept — quantum entanglement — in a semiconductor nanostructure known as a quantum dot.

Entanglement is arguably the most striking feature of quantum mechanics. Two systems, A and B, are said to be entangled if their quantum states are correlated — that is, not separable. This means that although we cannot predict what state system A will be in when it is measured, we can predict with certainty the measurement outcome of system B once A is measured, even if the two systems are separated by an arbitrarily large distance. This feature famously unsettled Einstein — who deemed it "spooky action at a distance" — and led to the renowned 'EPR' paper questioning the completeness of quantum theory[3].

In recent decades, with the advent of quantum information science[4], entanglement has evolved from being considered a counter-intuitive curiosity of quantum theory to being recognized as a key resource for quantum communication and computation. In particular, entanglement between a stationary quantum system and a 'flying' quantum system, such as a photon, has the potential to allow long-distance, secure communication and entanglement between two stationary systems that have never 'met' but that become linked by the flying system. Therefore, if quantum information processing is to become a practical reality, it is crucial to generate and quantify entanglement between viable physical systems. In recent years, such entanglement has been shown for trapped ions[5] and for certain defect states in diamond called nitrogen-vacancy centres[6].

Now, for the first time, De Greve *et al.* and Gao *et al.* demonstrate entanglement between a photon and a single electron spin trapped in a quantum dot. Formed at the interface between two semiconductors, the quantum dot has the ability to trap single electrons. Electrons confined in quantum dots remain in discrete, atomic-like spatial states without the need for external electromagnetic traps, and they have well-defined quantum properties. Once an electron is trapped in the dot, experimenters can focus on its spin, which can be in two distinct states ('up' or 'down') or, according to the superposition principle of quantum mechanics, in a linear combination of the two. In the beautiful experiments of De Greve *et al.* and Gao *et al.*, it is the electron's spin that becomes entangled with the polarization and the colour (frequency) of a photon, respectively. Polarization describes whether the light's electric field oscillates horizontally, vertically, in a circle or in any combination of these.

To generate the photon, both groups made use of the fact that quantum dots are optically active. First, the authors prepared the system using a technique called optical pumping, which amounts to depleting the spin-down state with a laser and pumping the spin into the up state. They then used a laser pulse of appropriate frequency and duration to excite the system to a higher-energy state and allowed it to 'relax' back to either one of the two lower-energy states. This kind of relaxation is accompanied by the spontaneous emission of a photon. With this process, the entire electron–photon system is in a superposition of two states: one in which the electron has spin-up orientation and the photon is blue and vertically polarized, and the other in which the electron has a spin-down orientation and the photon is red and horizontally polarized. The state of the emitted photon is completely quantum correlated (entangled) with the final electron spin state.

One problem with this kind of final state is that both the colour and polarization of the photon are correlated with the electron spin. For entanglement to be used in applications, only one of the two should be correlated. Therefore, both groups eliminated the unwanted correlation with the additional photon property. De Greve and colleagues downconverted the photon (that is, reduced its frequency by half), thereby broadening its frequency range. This step was crucial to obtaining the desired frequency state of the photon, because the correlation between electron spin and photon colour was erased as a result of having one, broadened frequency value instead of two, distinct, sharp ones. The remaining quantum entanglement was then solely between the electron spin and the photon polarization. The downconversion has the additional benefit of providing a photon that is at the wavelength used in telecommunications, in which lossless photon propagation in optical fibres can be extremely long. As a result, this experiment is an important first step towards achieving practical quantum networks[7] based on quantum-dot electron spins and photons.

Meanwhile, Gao and colleagues opted to use frequency as their entangled quantity, and so had to remove the correlation with polarization. They achieved this by 'filtering' the photon, regardless of its frequency, so that it acquired an anticlockwise, circular polarization. This eliminates the correlation with polarization, leaving an entangled state of photon colour and electron spin. Their filtering also solved the practical problem of separating the emitted photon from the vast number of photons emitted by the laser, which had a clockwise, circular polarization.

Using quantum dots as photon emitters has potential advantages over competing systems. Quantum dots have a higher electric dipole moment, leading to faster photon emission. What's more, they can be placed in optical microcavities to increase photon yield[8]. One avenue for future research would be the addition of a second, distant quantum dot to the authors' set-up, with joint measurement of the two emitted photons (one from the first quantum dot and the other from the second) to entangle the spins of the two dots[9]. Another possibility would be to 're-pump' a single quantum dot to extract a second photon, which under certain conditions will be entangled with the first. This idea could be extended[10] to produce multi-photon entangled states for 'measurement-based' quantum computing[11]. The present experiments pave the way to such demonstrations, and contribute to efforts to achieve large-scale, practical processing of quantum information. ■

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VASCULAR BIOLOGY

Nitric oxide caught in traffic

Nitric oxide is a vital signalling molecule that controls blood flow and pressure. Unexpectedly, a redox switch in the protein haemoglobin α within endothelial cells regulates this molecule's diffusion in blood vessels. **SEE LETTER P.473**

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Nitric oxide is a vasodilator. It is produced in endothelial cells, which line blood vessels, and mediates signalling cascades in adjoining smooth-muscle cells to affect the regulation of blood pressure, blood flow and oxygen delivery. Nitric oxide is proposed to control these crucial physiological processes through simple unregulated diffusion from its site of production to its target sites. But on page 473 of this issue, Straub and colleagues provide evidence[1] that the oxidation state of the protein haemoglobin α, which is expressed at the junction between endothelial and muscle cells, regulates nitric oxide diffusion and signalling*.

Haemoglobin is best known for mediating oxygen delivery by erythrocytes (red blood cells). Nonetheless, low concentrations of this protein are expressed in other cells, such as human lung epithelial cells[2]. In addition, over the past 15 years several primordial globins— including neuroglobin and cytoglobin — have been discovered that are expressed in various non-erythrocytic organs such as the brain, retina, endocrine organs and vascular smooth muscle. Functions that are being explored for these proteins include mediating electron-transfer reactions (such as the reduction of the enzyme cytochrome *c* and

*This article and the paper under discussion[1] were published online on 31 October 2012.