1. Title of Case Study: *Beating the Stoner criterion using molecular interfaces*

2. Grant Reference Number: *EP/K00512X/1*, EP/K036408/1, EP/I004483/1, EP/K013610/1

3. One sentence summary: *Non-magnetic metals turned into metals at room temperature*

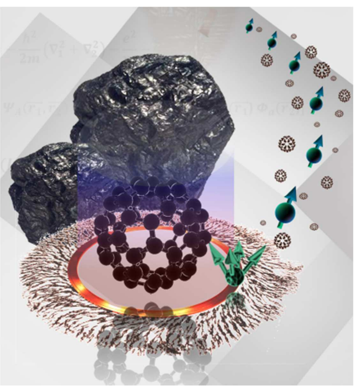
4. One paragraph summary*: Two common metals that are not magnetic — copper and manganese — can be transformed into magnets: a surprising effect that involves combining thin films of the metals with fullerene molecules. Density functional theory simulations suggest a mechanism based on magnetic hardening of the metal atoms, owing to electron transfer. The mechanism may allow for the design of magnetic materials and interfaces using abundant, non-toxic components such as organic semiconductors, with new possibilities for electronic, power or computing applications.*

5. Key outputs in bullet points:

- *Novel Physics beyond time-honoured eighty-year old models of ferromagnetism in metals.*
- *Major role of HEC Archer resources for the execution of the research*
- *Possibility of new transformative technologies for sustainable production of magnetic materials to be developed from the evidenced mechanisms.*

6. Main body text

Only three elements are ferromagnetic at room temperature: the transition metals iron, cobalt and nickel. The Stoner criterion explains why iron is ferromagnetic but manganese, for example, is not, even though both elements have an unfilled 3d shell and are adjacent in the periodic table: according to this criterion, the product of the density of states and the exchange integral must be greater than unity for spontaneous spin ordering to emerge. This research has demonstrated that it is possible to alter the electronic states of non-ferromagnetic materials, such as diamagnetic copper and paramagnetic manganese, to overcome the Stoner criterion and make them ferromagnetic at room temperature. This effect is achieved via interfaces between metallic thin films and fullerene C_{60} molecular layers. The emergent ferromagnetic state exists over several layers of the metal before being quenched at large sample thicknesses by the material's bulk properties. Although the induced magnetization is easily measurable by magnetometry, low-energy muon spin spectroscopy provides insight into its distribution by studying the depolarization process of low-energy muons implanted in the sample. This technique indicates localized spin-ordered states at, and close to, the metal–molecule interface. Density functional theory simulations suggest a mechanism based on magnetic hardening of the metal atoms, owing to electron transfer. This mechanism might allow for the exploitation of molecular coupling to design magnetic metamaterials using abundant, non-toxic components such as organic semiconductors. Charge transfer at molecular interfaces may thus be used to control spin polarization or magnetization, with consequences for the design of devices for electronic, power or computing applications.



Artistic representation of the onset of magnetic spin-ordering at the interface between non-magnetic cheap substrates such as metal Manganese (or Copper) and fullerene C_{60} molecules. Courtesy of Fatma Al Ma'Mari, Timothy Moorsom, and Oscar Cespedes (Department of Physics, University of Leeds).

Reference: F. Al Ma'Mari et al., *Beating the Stoner criterion using molecular interfaces*, Nature 524, 69-73 (12015). doi:10.1038/nature14621

7. Names of key academics and any collaborators:

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8. Sources of significant sponsorship (if applicable):

EP/K00512X/1. *Multidisciplinary extreme magnetometry: State of the art magnetometry for physical, chemical, biological and engineering applications.*

EP/K036408/1. *INSPIRE Physical Sciences: A synergy for next generation materials science.*

EP/I004483/1. *In-silico development of the potential of doped metal-oxide nanotubes as novel photo-catalysts for energy applications (Career Acceleration Fellowship).*

EP/K013610/1. *Support for the UKCP consortium.*

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