



# Intersections

Henry Moore and stringed surfaces

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EXCELLENCE  
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THE ROYAL SOCIETY



Isaac Newton Institute  
for Mathematical Sciences

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*Intersections* features the work of Henry Spencer Moore (1898 – 1986), displayed with models from the Science Museum and modern scientific imagery. The exhibition is in joint London venues: the Science Museum's Mathematics Gallery and the Royal Society's President's Gallery, both under the auspices of the Isaac Newton Institute for Mathematical Sciences.

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The Royal Society and The Isaac Newton Institute would like to thank the following organisations for their generous support of the exhibition:

The Henry Moore  
Foundation



The 29th May 1961  
Charitable Trust

# Intersections: Henry Moore and stringed surfaces

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## Olivier's String Models

The great French mathematician Gaspard Monge (1746 – 1818) invented what came to be called descriptive geometry and illustrated his discoveries using surfaces created by stretching strings across a curved frame. In mathematics these are called ruled surfaces because through every point there is at least one, sometimes more than one, straight line which lies on the surface. Cones and cylinders are obvious examples but there are many others.

The pedagogical application of Monge's string models was taken up by his pupil Théodore Olivier (1793 – 1855) who used articulated frames with moveable components, as exemplified in this exhibition, to visualise a wide variety of surfaces simultaneously using different coloured strings. Olivier was famous for his exquisite models, which were sold and copied throughout Europe and in the United States. He was practically minded and large collections of his models were acquired by engineering departments, from the University of Arizona to the US Military Academy at West Point. These institutions were eager to assimilate for the benefit of their students the latest design technology, the equivalent in their time of modern computer graphics and computer-aided design.

As an example, Olivier was able to illustrate to his students curves in three dimensions that were created by the intersection of two ruled surfaces. Indeed, it was this feature that caught the eye of a young Henry Moore when, as a student at the Royal College of Art, he visited the Science Museum in London, which houses a collection of Olivier string models.

## String Theory

In Olivier's models the strings are fixed in space. The surfaces they create relate to a branch of pure mathematics which concerns itself with how "singularities" such as cusps and corners can be created from collections of smooth objects such as straight lines and planes. By way of contrast, String Theory is a branch of mathematical physics in which the fundamental concept is a string which vibrates in space.

String Theory emerged from various attempts to unify our understanding of the physical world and to address the deep problem of how to make the quantum mechanics of Heisenberg and Schrödinger consistent with Einstein's theory of relativity. In the so-called Standard Model of particle physics (not, of course, a mechanical model like Olivier's, but a model in the sense of a mathematical theory that predicts the outcomes of experiments), particles are

regarded as points identified in space and time not only by their position, velocity, mass and electric charge, but also by their colour, (the "charge" associated with the strong nuclear interactions) and their spin. The Standard Model successfully incorporated three of the four known natural forces: electromagnetism, and the strong and weak nuclear forces. However the important force of gravity, which is described by the theory of general relativity, was not included. One aim of String Theory is to resolve this problem.

In String Theory different modes of vibration of strings represent particles with various properties, including the graviton, which is the quantum particle associated with the force of gravity. Consequently String Theory is a leading candidate for the reconciliation of general relativity and quantum mechanics. However it has turned out that a fully consistent String Theory, which contains matter particles such as quarks and electrons as well as force particles like photons, gravitons and gluons, requires ten space-time dimensions. Because the world in which we live appears to have only four space-time dimensions, a conjecture is that the space occupied by the other dimensions of String Theory is tightly curled up in the form of a six-dimensional Calabi–Yau manifold, a sophisticated geometric object discovered and studied only in the second half of the last century.

String Theory is a highly active area of current research in which open questions in fundamental physics are formulated and examined in the sophisticated language of modern mathematics. At the Isaac Newton Institute for Mathematical Sciences, which sponsors this exhibition, there is ongoing research on M-theory, an eleven-dimensional extension of the theory that includes not just strings but membranes and other extended objects.

## The Isaac Newton Institute for Mathematical Sciences

Twenty years ago the Isaac Newton Institute in Cambridge was created with the remit of nurturing and contributing to the already very high standing of the United Kingdom in the world of research mathematics. No scientific or societal topic with significant mathematical content was to be excluded a priori from its activities and, because of its modest size, scientific merit was to be the major factor in choosing what research it would support. Since then it has become one of the leading mathematical research institutes in the world. A landmark in the history of the Institute was the announcement there by Sir Andrew Wiles of his strategy for proving Fermat's Last Theorem which had been an open question in number theory for 350 years.

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Research in mathematics tends to consist of major breakthroughs, with rapid exploitation of new ideas, followed by long periods of consolidation. The Isaac Newton Institute has established itself as an important world centre by focussing on breakthroughs rather than consolidation. The Institute therefore chooses to support fields whose importance and diversity are likely to have significant long-term impact involving world leaders in research, often from very different backgrounds.

Intersections are crucial to the work of the Institute. The Institute has hosted programmes in areas as diverse as the mathematical aspects of astronomy, biology, economics, epidemiology, finance, materials science, medicine, meteorology, networks, oceanography and particle physics and bringing together researchers with different backgrounds and experience has yielded insights that neither discipline

could have achieved if working in isolation. To quote the Institute's founding Director, Sir Michael Atiyah OM: "If you attack a mathematical problem directly, very often you come to a dead end, nothing you do seems to work and you feel that if only you could peer round the corner there might be an easy solution. There is nothing like having somebody else beside you, because he can usually peer round the corner."

The common thread running through the Institute's research programmes is leading edge mathematics of the highest standard in the world.

**John Toland FRS**

Isaac Newton Institute for Mathematical Sciences,  
Cambridge



# Introduction

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“To know one thing, you must know the opposite.”

Henry Moore

To say that mathematics and art have a long historical relationship is to state nothing new. Not even by suggesting that for thousands of years artists as well as mathematicians have been interested in geometric forms do we make a claim for groundbreaking insight. It is evident that mathematicians have been drawing and modelling these forms as a tool for investigating ideas of spaces for centuries, and for other artists and thinkers such forms have long represented ideals of perfection and truth.

However, the mid to late nineteenth century was a revolutionary time in mathematics, when conventional ideas, such as Euclidean geometry, were being turned on their heads. During this period mathematicians began to produce less regular and more startling geometric figures. Many of these new and exciting mathematical ideas filtered into the public sphere and sparked the imagination of writers and artists alike. For example, writers such as H.G. Wells and artists like Marcel Duchamp were fascinated with non-Euclidean geometry and the idea of a spatial fourth dimension. The surrealists found that “non-Euclidean geometry signified a new freedom from the tyranny of established laws”.<sup>1</sup> Mathematics, in this way, represented both progress and the potential for chaos.

The two major artistic movements of the following period, the surrealists and the constructivists, appear to have discovered geometric mathematical models around the same time. Surrealist photographer and painter Man Ray produced a series of photographs in 1936 of mathematical models housed at the Poincaré Institute in Paris, while the Constructivist Naum Gabo began to draw direct inspiration from the forms of mathematical models in the early 1930s. In his 1936 book, *Cubism and Abstract Art*, Alfred Barr made even more of Gabo's connection with models, stating that Gabo “had been studying mathematics in Munich and had made mathematical models”, although the evidence for this statement is unclear.

The influence of these encounters between avant-garde art and mathematics extends to Britain through a number of routes. One such path is through the work of Barbara Hepworth, who had contact with Naum Gabo while the artist was in England during 1936 – 1946. Yet, Hepworth may have seen mathematical models before she encountered Gabo. In December 1935, Hepworth sent a letter to her husband Ben Nicholson in which she said that architect John Summerson had told her that there were “some marvelous things in a mathematical school in Oxford -- sculptural working out of mathematical equations -- hidden away in a cupboard” and that she intended to go and look at them soon.<sup>2</sup> A number of Hepworth's work exhibit mathematical influence, for instance the sculpture *Pelagos* (1946), echo mathematical models both in their form and in their use of string. During the 1930s, Hepworth was producing sculptures using string and plaster – both materials were unusual for sculpture of the time, and both were materials widely used in the mathematical models that would have been displayed in many universities and museums.

In parallel to the work of Hepworth, Henry Moore was also using plaster and string to create strange and beautiful forms. Indeed, Moore stated on several occasions that the use of string in his sculpture, which began in 1937, was influenced by seeing models at the Science Museum in London: “I was fascinated by the mathematical models I saw there, which had been made to illustrate the difference of the form that is halfway between a square and a circle. One model had a square at one end with 20 holes along each side...Through these holes rings were threaded and lead to a circle with the same number of holes at the other end. A plane interposed through the middle shows the form that is halfway between a square and a circle...It wasn't the scientific study of these models but the ability to look through the strings as with a bird cage and see one form within the other which excited me.”<sup>3</sup>

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1 Henderson, L. (1983) *The Fourth Dimension and Non-Euclidean Geometry in Modern Art*. Princeton: Princeton University Press. p. 339.

2 Hammer, M. and Lodder, C. (1996). Hepworth and Gabo: a Constructivist Dialogue. In D. Thistlewood (ed.) *Barbara Hepworth Reconsidered*. Liverpool: Liverpool University Press (pp. 109 – 133).

3 Hedgecoe, J. and Moore, H (1968). *Henry Spencer Moore*. New York: Simon and Schuster. p. 105.

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That encounter between the nineteenth century stringed surfaces of Théodore Olivier cited by Moore, and the work that resulted from that influence is the subject of this exhibition. Yet, *Intersections* is also an exhibition about how individuals, from diverse disciplines, think through problems visually in order to discover new solutions and forms. More widely, through our own encounter with these strange and beautiful works of mathematics and art we glimpse a shared conversation between these separate disciplines, and find creativity common to both.

Moore's string figures, the stringed surfaces of Théodore Olivier and computer graphics illustrating Calabi–Yau manifolds are all visual representations of mathematical structures that arise in String Theory. Through shared, yet at times opposing, approaches to a simple string, this exhibition explores fascinating intersections between mathematics and art. Moreover, as the title of the exhibition suggests, in mathematics, the intersection of two sets is the collection of points, often illustrated by a Venn diagram, which are common to both.

**Barry Phipps**

Churchill College, Cambridge

# The history of mathematical surface models

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The makers of the mathematical surface models were inspired by the usefulness of mathematics as a foundation for the industrial arts. Henry Moore and his contemporaries were inspired by the beauty of mathematics as a springboard for the creation of artistic forms. Mathematics and the arts have often been entwined, and one such confluence occurred in Revolutionary France.

The sculptures are constrained by the aesthetic sensibilities of the sculptor, but the mathematical surface models are constrained by mathematical forms described by equations. Mathematical solid models have a long history<sup>1</sup>. However, interest in surfaces and the construction of surface models only began at the end of the eighteenth century, and went hand in hand with a change of social use and therefore audience<sup>2</sup>. During the nineteenth century, the 'great age of surface building' gave rise to collections of exquisite and complex models in universities and museums across Europe and North America<sup>3</sup>.

The study of surfaces themselves was prompted by the desire to find geodesics, the shortest paths between two points on a surface, particularly that of the Earth<sup>4</sup>. Another requirement for a knowledge of surfaces was that of map-making<sup>5</sup>. The belief that 'nature is thrifty in all its actions' gave rise to the study of minimum surfaces<sup>6</sup>. In particular Leonard Euler discovered the 'catenoid', the surface of minimum area between two circles<sup>7</sup>.

However, developments in the organisation of mathematics are the key to the actual production of models. In France, the founding of the Ecole Polytechnique was crucial. There students had the best mathematicians of the time; Lagrange, Laplace, Fourier, and Poisson to name a few. The person who created a new discipline, Descriptive Geometry, and appears to have made the first surface models, was Gaspard Monge<sup>8</sup>. Monge wanted to "generalise all the isolated methods hitherto employed, not merely in fortification but in perspective, dialling, stone-cutting etc into a theoretical code". He introduced geometrical thinking back into mathematics, putting it on an equal basis with analysis and inspiring the revival of pure geometry. We know he had two models of silk thread which were extant in 1814<sup>9</sup>, however, unlike the extant models they were fixed.

In 1830 a pupil of Monge, Theodore Olivier, designed a series of models which overcame this difficulty.<sup>10</sup> These models could be distorted and rotated thus providing a variety of geometrical configurations. We have a set of about 30 in the mathematics collection of the Science Museum,<sup>11</sup>. These were made by Fabre de Lagrange of Paris in 1872. Olivier's personal set were sold after his death in 1853 to Union College Schenectady, New York, whose set were copied for Princeton as late as 1882. C.W. Merrifield wrote: 'These surfaces, on account of the facility with which they can be constructed and represented, and of the ease with which their intersections can be determined, are of more consequence than any others in the geometry of the Industrial Arts.'<sup>12</sup>

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- 1 See 2005-53 in the Mathematics Gallery of the Science Museum, and the trade card of Edward Scarlet in Calvert H.R. *Scientific Trade Cards in the Science Museum Collection*, 1971.
  - 2 Lawrence, Snezana 'History of Descriptive Geometry in England' in *Proceedings of the First International Congress on Construction History*, Madrid, 20th – 24th January 2003.
  - 3 Sakarovich, Joel. 'Epures D 'Architecture' 1997. Fischer, Gerd 'Mathematische Modelle/Mathematical Models' 1986, Mehrtens, Herbert 'Mathematical Models' in *The Third Dimension of Science* ed Soraya Chadarevian and Nick Hopwood 2004.
  - 4 The contributors were John and James Bernoulli, Alexis Clairaut and Leonard Euler in 1697, 1733 and 1760 respectively.
  - 5 Euler, Leonard in *Novi Commentari Academiae Scientiarum Imperialis Petropolitanae* vol 16 1771 op vol 1 section 28 p.161-186
  - 6 These studies were influenced by Maupertuis, Pierre Louis Moreau 'Accord de différentes loix de la nature qui avoient jusqu'ici paru incompatibles' 1744

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In Germany from the 1860s there developed an interest in constructing models to represent the furthest frontiers of research. This was a very different level of mathematics from that illustrated by the French models. In 1868 Julius Plucker had made a large collection of surfaces, some of the fourth order<sup>13</sup>. The mass production of surface models also became a German phenomenon with the establishing of production at Munich by Alexander von Brill<sup>14</sup>.

The use of models influenced the organisation of mathematics. It became imperative for any self-respecting University to buy a collection from the 1870s onwards. The models had to be kept somewhere which gave rise to mathematics teaching collections like the one held at the Science Museum, and dictated the ambience of the lectures. The models dictated the staffing of institutions as there was a need for 'conservators' to care for them.

Production of surface models died out at around the time of WW1. This was possibly because of general disruption to all production, possibly because class sizes were bigger and the models are fragile, possibly because after equations of the fourth power that particular seam was exhausted. Fortunately they have remained on display at the Science Museum ever since to inspire new avenues of creativity.

**Jane Wess**  
Science Museum

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- 7 Kline, Morris *Mathematical Thought From Ancient to Modern Times*, Oxford University Press, 1972. p.579. Euler, Leonard 'The Art of Finding Curved Lines Which Enjoy Some Maximum or Minimum Property'. 1744
- 8 Taton, René. *L'Oeuvre Scientifique de Monge*. Paris. 1951.
- 9 Catalogue des Collections du Musee des Arts et Metiers. 1906.
- 10 Fink, Karl A *Brief History of Mathematics* 1910 p.277
- 11 Inv numbers originally ran from 1872-93 to 135, some have been disposed of.
- 12 Merrifield C.W. 'Catalogue of a Collection of Models of Ruled Surfaces constructed by Fabre De Lagrange' 1872. p.3
- 13 Inv number 1876-508 'Fourteen boxwood models of quartic surfaces'. Some are on display in the Mathematics Gallery.
- 14 W. Dyck. *Katalog Mathematischer und Mathematisch Physikalischer Modelle, Apparate, und Instrumente* (Reprint)., 1994. Originally in 1892.



## The exhibits

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It may say something profound that stretched strings sometimes illustrate complicated geometry, inspire great sculpture and arise in a mathematical theory to explain the particles and forces in our universe. Inspiration from simplicity is the hallmark of great art and of great science.

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### ***String surface model: conoids***

by Fabre de Lagrange, 1872

Two equal circles in parallel planes, divided equidistantly, are connected by threads, so as to form a cone, a cylinder, a conoid, a second conoid.

Science Museum inventory number: 1872-113

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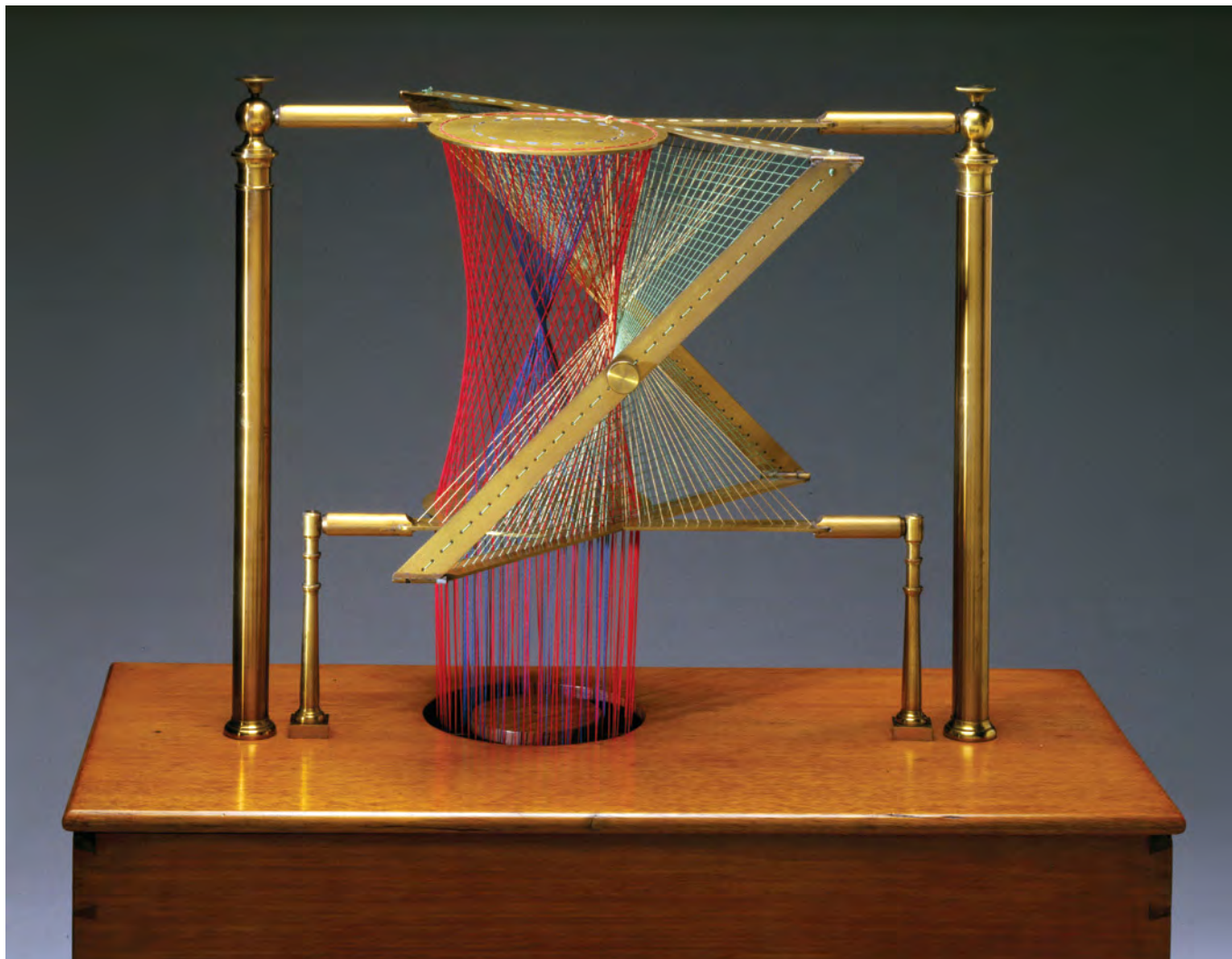
### ***String surface model: Conoids***

by Fabre de Lagrange, 1872

The same arrangement as inventory number 1872-113 (opposite) except that the lower ring is replaced by a plane of section a little higher up.

Science Museum inventory number: 1872-114

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(Above)

***String surface model: hyperboloid and asymptotic cone***

by Fabre de Lagrange, 1872

Hyperboloid of one sheet, with its asymptotic cone; the tangent plane to the cone is also drawn.

Science Museum inventory number: 1872-104

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(Left)

***String surface model: conoid***

by Fabre de Lagrange, 1872

Conoid in contact with a hyperbolic paraboloid.

Science Museum inventory number: 1872-112

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***String surface model: hyperbolic paraboloid***

by Fabre de Lagrange, 1872

A skew quadrilateral with its opposite sides equal in length and pierced with holes at equal distances.

Science Museum inventory number: 1872-96

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***String surface model: geometrical groin vault***

by Fabre de Lagrange, 1872

Oblique intersection of two splayed vaults of the same spring.

Science Museum inventory number: 1872-129

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***String surface model: conoids***

by Fabre de Lagrange, 1872

Model showing the transformation of a cylinder into a conoid and back again, and also the transformation of a cone into a conoid and back again.

Science Museum inventory number: 1872-110

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***String surface model: staircase vault***

by Fabre de Lagrange, 1872

Model for exhibiting some properties of this ruled surface by showing how it is obtained from the deformation of a cylinder.

Science Museum inventory number: 1872-119

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(Above left)

***String surface model: common groin***  
by Fabre de Lagrange, 1872

Intersection of two cylinders having a pair of common tangents; the model may be set square or oblique.

Science Museum inventory number: 1872-124

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(Above)

***Stringed Figure***  
by Henry Moore, 1938

Bronze and elastic string

Size: 273 x 343 x 197mm

Private collection

Image © The Henry Moore Foundation

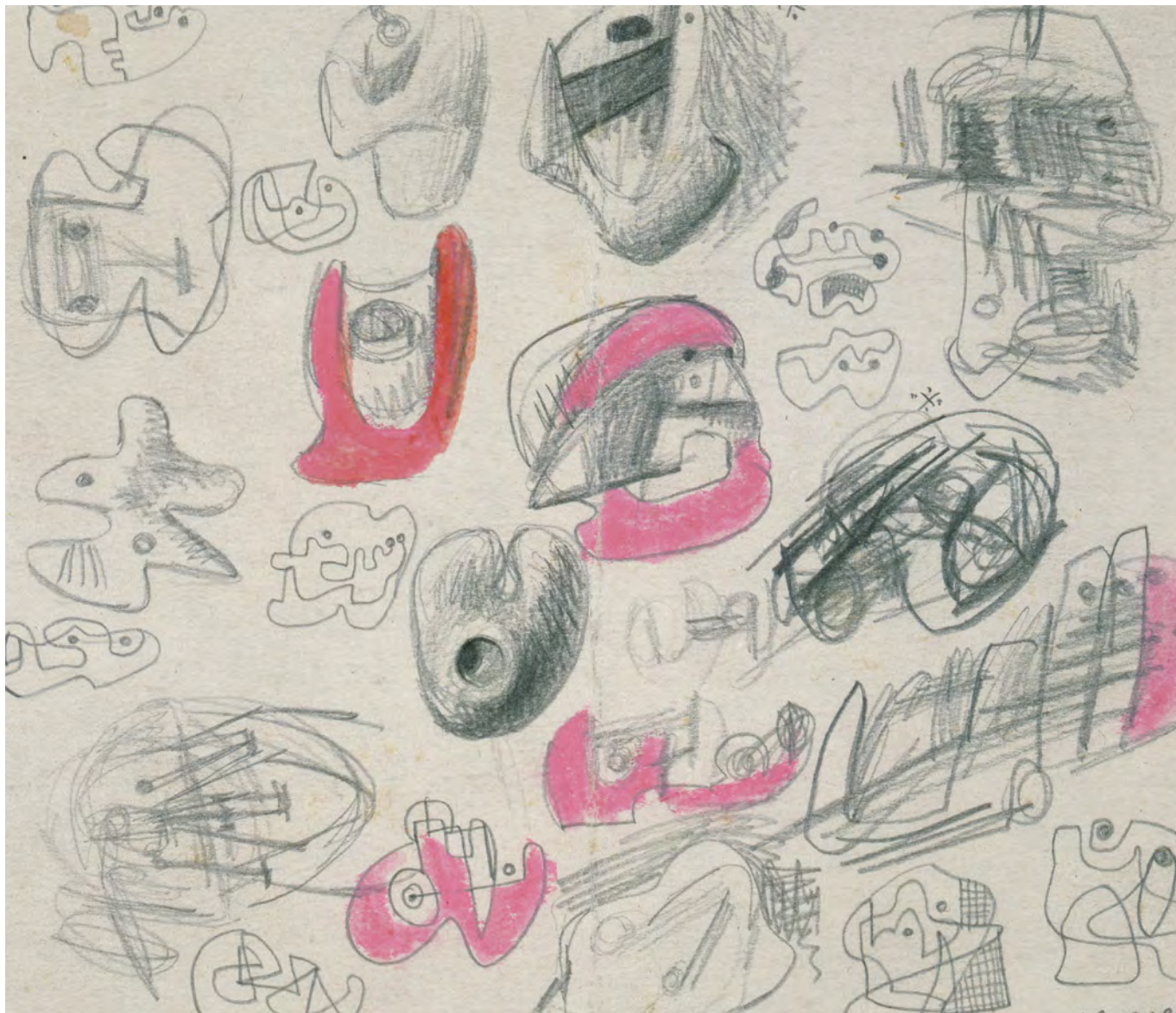
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***String surface model: hyperbolic paraboloid***  
by Fabre de Lagrange, 1872

Two bars equally spaced, each turns on an arm perpendicular to itself and one arm swings on a pillar; these arms can be ranged in one plane, and also turned end for end.

Science Museum inventory number: 1872-93

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(Above)

***Ideas for Sculpture***  
by Henry Moore, 1938

Pencil, crayon, watercolour on cream lightweight card

Size: 166 x 190mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1274

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(Right)

***Ideas for Sculpture*** 1938  
by Henry Moore, 1938

Pencil, crayon on cream lightweight card

Size: 166 x 190mm

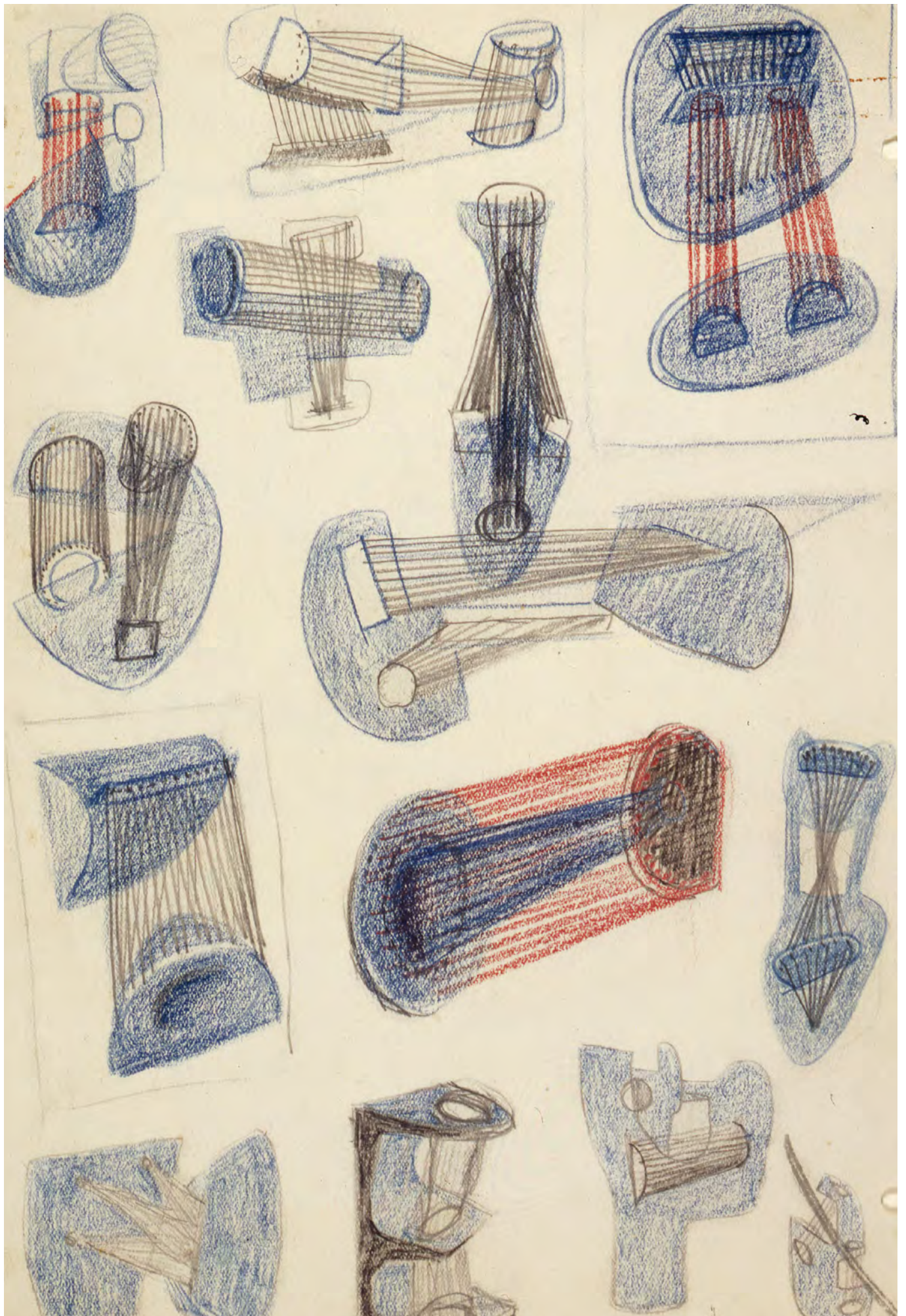
The Henry Moore Foundation: gift of the artist 1977

HMF 1275

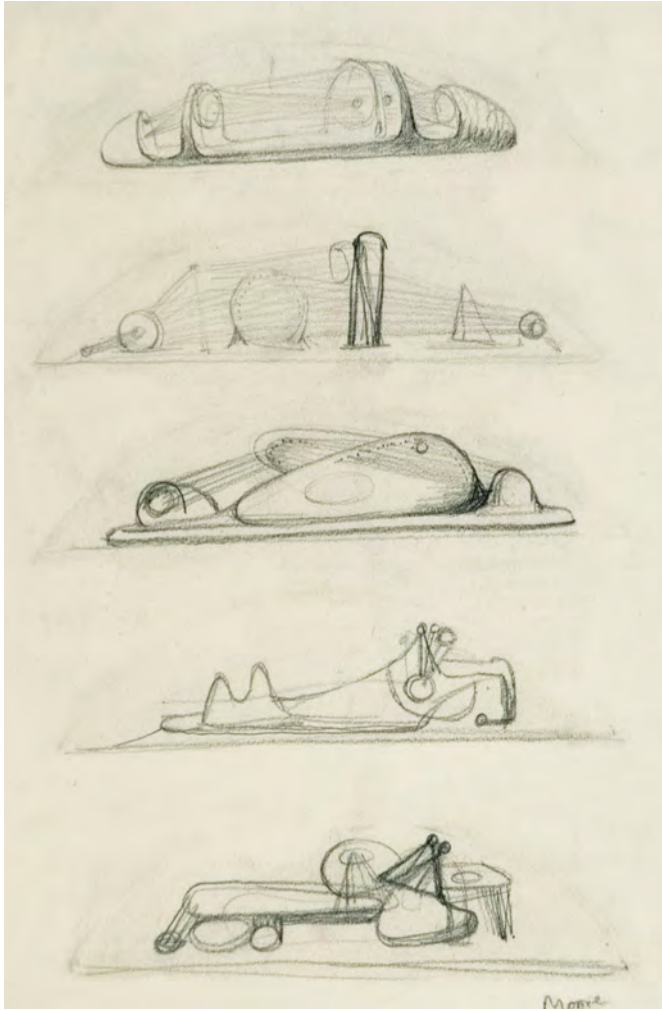
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***Ideas for Sculpture for Lubetkin's Flat:  
Stringed Figures***

by Henry Moore, 1938

Pencil on cream medium-weight wove

Size: 278 x 184mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1400



***Ideas for Stringed Figures***

by Henry Moore, 1938

Pencil on cream medium-weight wove

Size: 279 x 184mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1404

(Opposite)

***Ideas for Stringed Figure Sculptures***

by Henry Moore, 1937

Pencil, crayon, pen and ink on cream medium-weight wove

Size: 277 x 190mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1338









***Ideas for Sculpture***

by Henry Moore, 1938

Pencil, conté crayon on cream medium-weight wove

Size: 277 x 183mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1411



***Ideas for Sculpture***

by Henry Moore, 1938

Pencil, conté crayon on cream medium-weight wove

Size: 278 x 190mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1412

(Opposite)

***Ideas for Sculpture***

by Henry Moore, 1938

Pencil, conté crayon, charcoal, watercolour wash on cream medium-weight wove

Size: 277 x 183mm

The Henry Moore Foundation: gift of the artist 1977

HMF 1410



***Stringed Figure: Bowl***

by Henry Moore, 1938

Bronze and string edition of 9 + 1

Cast: The Art Bronze Foundry, London 1967

Height 546mm

The Henry Moore Foundation: gift of the artist 1979

LH 186c



***Stringed Figure***

by Henry Moore, 1938

Lead and yellow string

Height 171mm

Unsigned

The Henry Moore Foundation: acquired 1994

LH 186e

(Opposite)

***Stringed Relief***

by Henry Moore, 1937

Bronze and nylon edition of 2 + 1

Cast: Fiorini, London 1976

Length 495mm

The Henry Moore Foundation: gift of the artist 1977

LH 182





(Above)

***Mother and Child***

by Henry Moore, 1938

Bronze and red string edition of 9 + 1

Cast: Fiorini, London 1985

Height 95mm

The Henry Moore Foundation: acquired 1987

LH 186



(Above)

***Mother and Child*** 1938

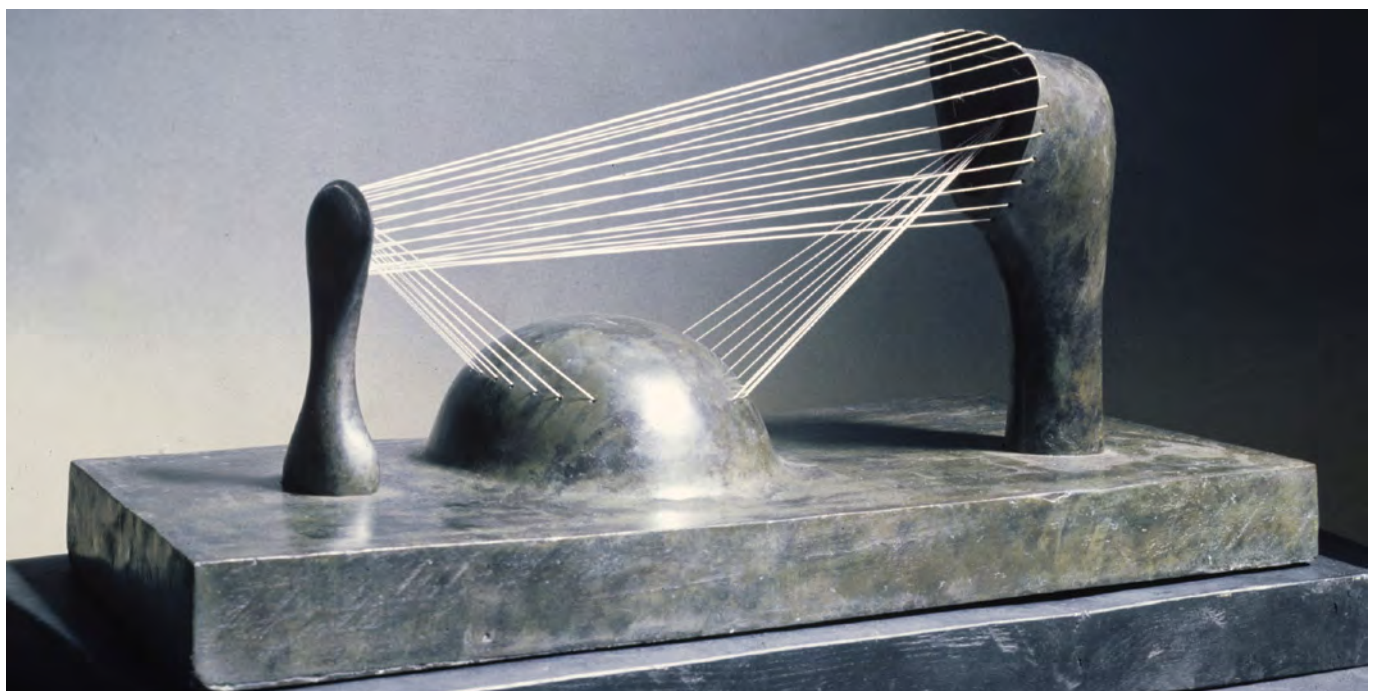
by Henry Moore, 1938

Lead and yellow string

Height 95mm

The Henry Moore Foundation: acquired 1996

LH 186





(Above)

### ***Stringed Ball***

by Henry Moore, 1939

Bronze and string edition of 7

Cast: [probably] The Art Bronze Foundry, London

Length 89mm

Unsigned, unnumbered

The Henry Moore Foundation: gift of the artist 1977

LH 198



(Above)

### ***Head***

by Henry Moore, 1939

Bronze and string edition of 6 + 1

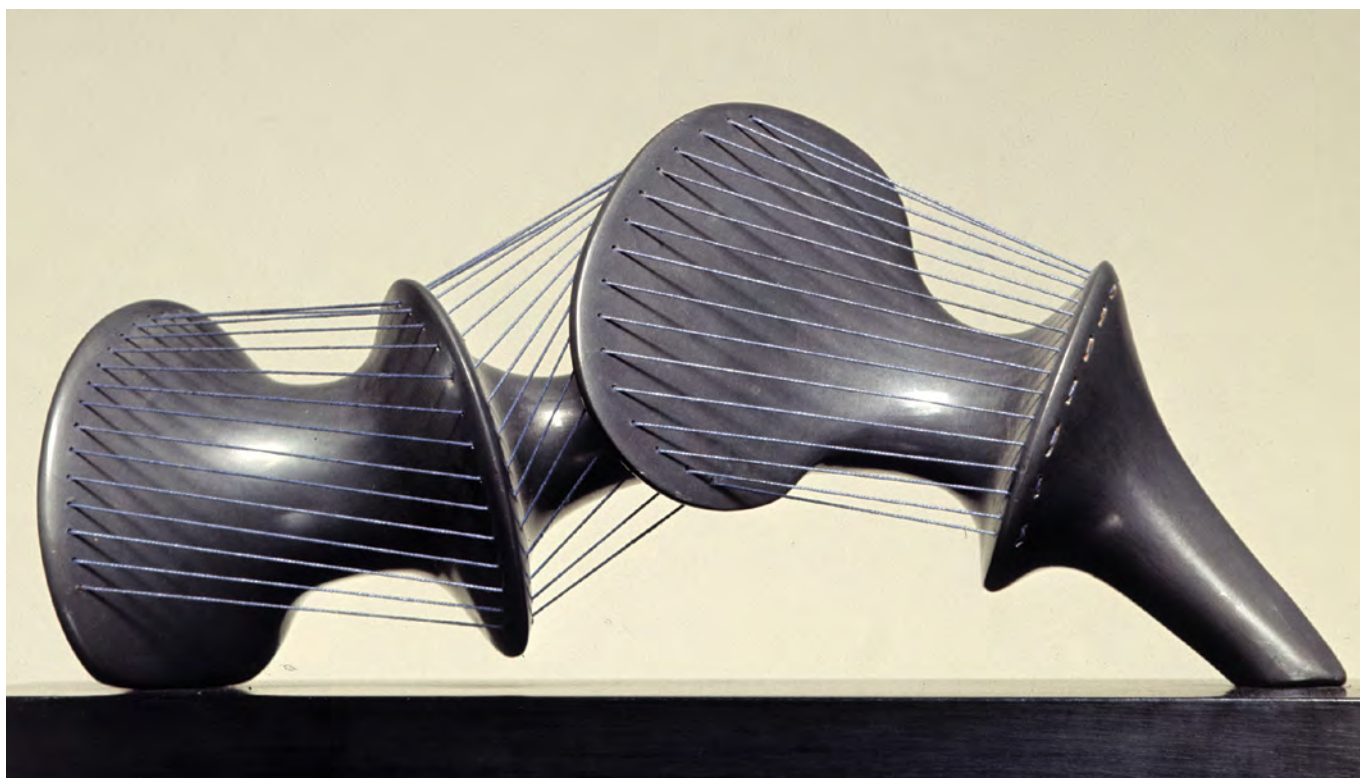
Cast: The Art Bronze Foundry, London 1968

Height 137mm

Signature: stamped Moore, 6/6

The Henry Moore Foundation: gift of the artist 1977

LH 195







(Above)

(Opposite)

***Stringed Figure***

by Henry Moore, 1939

Lead and violet string

Length 254mm

Unsigned

The Henry Moore Foundation: gift of Irina Moore 1977

LH 206

***Stringed Head***

by Henry Moore, 1938

Bronze and string edition of 5 + 1

Cast: Fiorini, London 1966

Height 111mm

Signature: marked Moore, [0/5]

The Henry Moore Foundation: gift of the artist 1977

LH 186g

# Acknowledgements

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This exhibition has been an extraordinary undertaking, representing the collaboration of some of Britain's finest institutions, The Isaac Newton Institute for Mathematical Sciences, The Royal Society, The Henry Moore Foundation and the Science Museum. Achieving such a wide-ranging exhibition has required a diverse and high level of skill from staff across these collaborating institutions and we thank in particular Sara Wilkinson and Christine West of the Isaac Newton Institute, Jane Wess and Boris Jardine of the Science Museum, Anita Feldman, Theodora Georgiou and Suzanne Eustace of the Henry Moore Foundation and Keith Moore, Daisy Barton and Karen Newman of the Royal Society.

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- Professor Dawn Ades, OBE, FBA, Trustee of the Henry Moore Foundation;
- The staff and officers of the Henry Moore Foundation and of the Science Museum for the loan of the exhibits;
- The Royal Society for hosting the exhibition;
- Dr Nicholas Mee for his virtual images.

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