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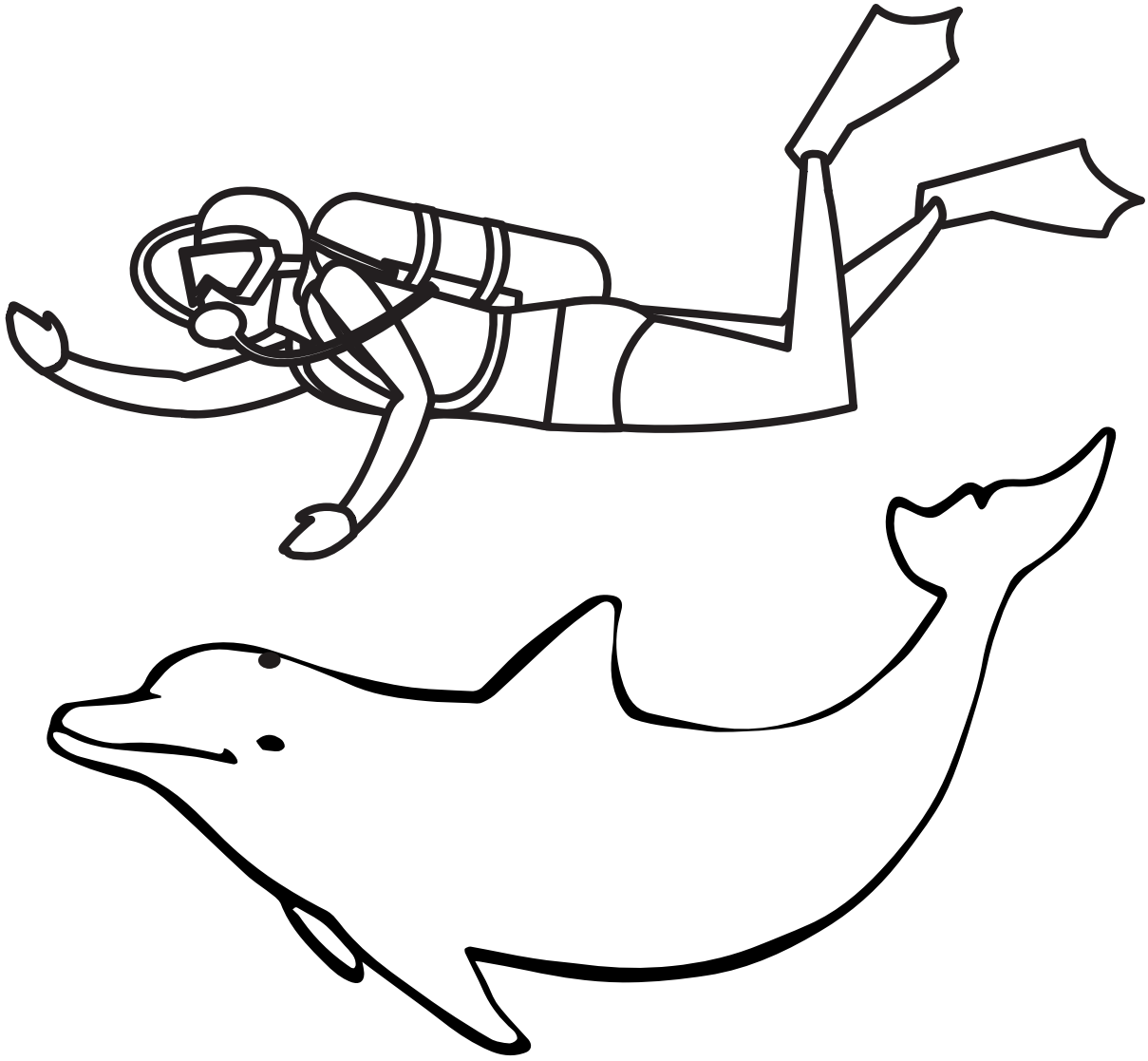
FOUNDATION

UNDER PRESSURE

ACTIVITY BOOK



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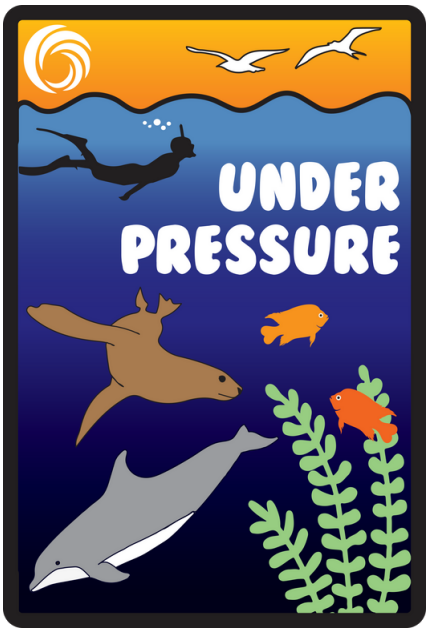

Under Pressure is a unit of the signature *Dolphin Doctor* educational program created by the National Marine Mammal Foundation with funding from the Office of Naval Research to inspire the next generation of Science, Technology, Engineering, Art, and Math (STEAM) professionals.

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HYPOTHESIS TIME!

BELL JAR EXPERIMENT

Step 1: Connect the syringe to the hoses with a one way valve.
Step 2: Connect the end of the plastic hose to the base of the bell jar.
Step 3: Put a small balloon on the base
Step 4: Place the jar upside down on the base over the balloon
S**tep 5:** Use the syringe to pump the air out of the jar

Repeat steps 1-5 with (1) a balloon, (2) a suction cup placed on the bottom of the jar, (3) a cup of water with a dropper in it, (4) a marshmallow, (5) a cup of warm water.

Record your **observations** and make a **hypothesis** about what is happening in the jar:

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FIRST DOLPHIN SELFIE TAKEN AT A DEPTH OF 300 METERS!

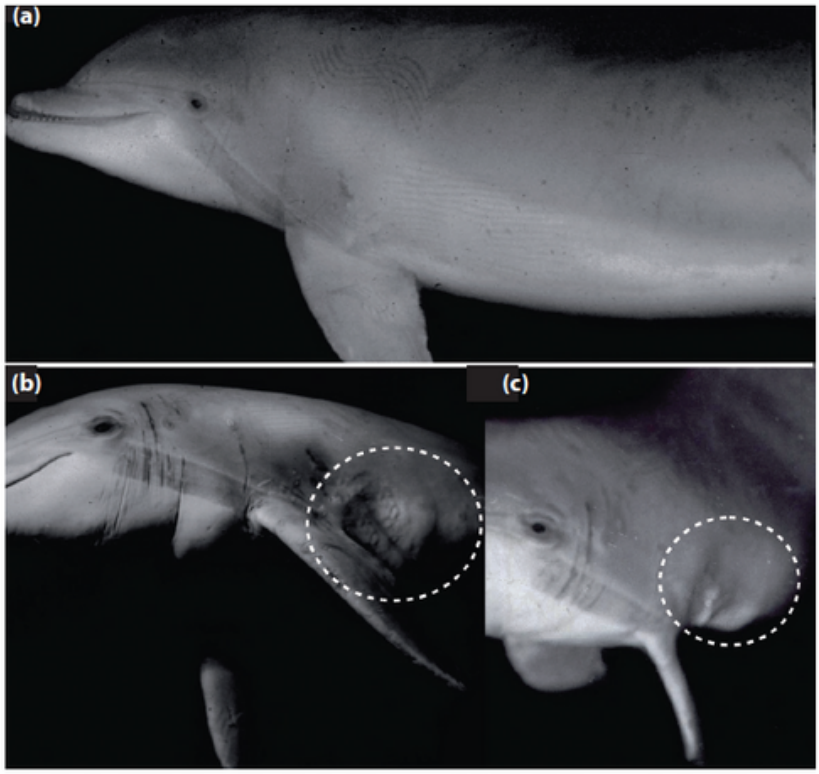

Fig. 2. In 1969, the Atlantic bottlenose dolphin Tuffy was trained to dive 300 m and press its rostrum to a paddle that activated a camera to take its picture. (a) Tuffy at surface, (b) and (c) Tuffy at 300 m depth; (b) and (c), the first dolphin selfies, revealed a dramatic collapse in its thoracic cavity (signified by dotted circles). (Photo courtesy of the U.S. Navy)

Taniguchi, D. A., Rohr, J., Ridgway, S., & Schulz, K. (2019). Two Beakers, Five E's, Twenty Pennies, and Archimedes' Principle. The Physics Teacher, 57(3), 138-141.

What do you notice in these pictures?

Living under the ocean has consequences. This is a dolphin named Tuffy who was trained to dive to 300 meters and take a flash photograph of himself. The pressure of the water above collapsed Tuffy's rib cage, greatly reducing the volume and buoyancy of his lungs (AND also helping to prevent the bends and nitrogen narcosis).

On land, you can say we live under an "ocean" of air. If you blow on your hand you feel your exhalation because air is made of molecules (matter) and in a gravitational field, that results in weight.

Air does not weigh much, but there is about 68 miles above you and that results in about 15 pounds per square inch (33% of air at the top of Mount Everest*).

We can experiment by exhausting most of the air within this bell jar:

The bell jar cannot be opened once all air inside has been pumped out because outside pressure is much greater than that inside. Balloons expand, not because we are adding inside the balloon, but reducing the pressure outside the balloon (around the balloon). Now, let air back in and the balloon returns to normal.

Marshmallows have lots of air pockets inside with air at a normal pressure (since that was the pressure of air at the factory). Reduce outside pressure and like a balloon the marshmallow expands. However, unlike the balloon, some of the air escapes (because of the internal air pockets). Therefore, when air is let in back into the bell jar, the marshmallow becomes crushed by the outside pressure entering back in.

HYPOTHESIS TIME!

BLUBBER EXPERIMENT

Step 1: Put one hand in the bag surrounded by blubber (actually cooking lard) and the other hand in ice water. What do you notice?

Step 2: Use the dual thermometer to measure the temperature of the ice water and inside the submerged blubber. Record the two temperatures. Why do you think blubber is such a good insulator?

Ice Water Temerpature: **Blubber Temperature:**

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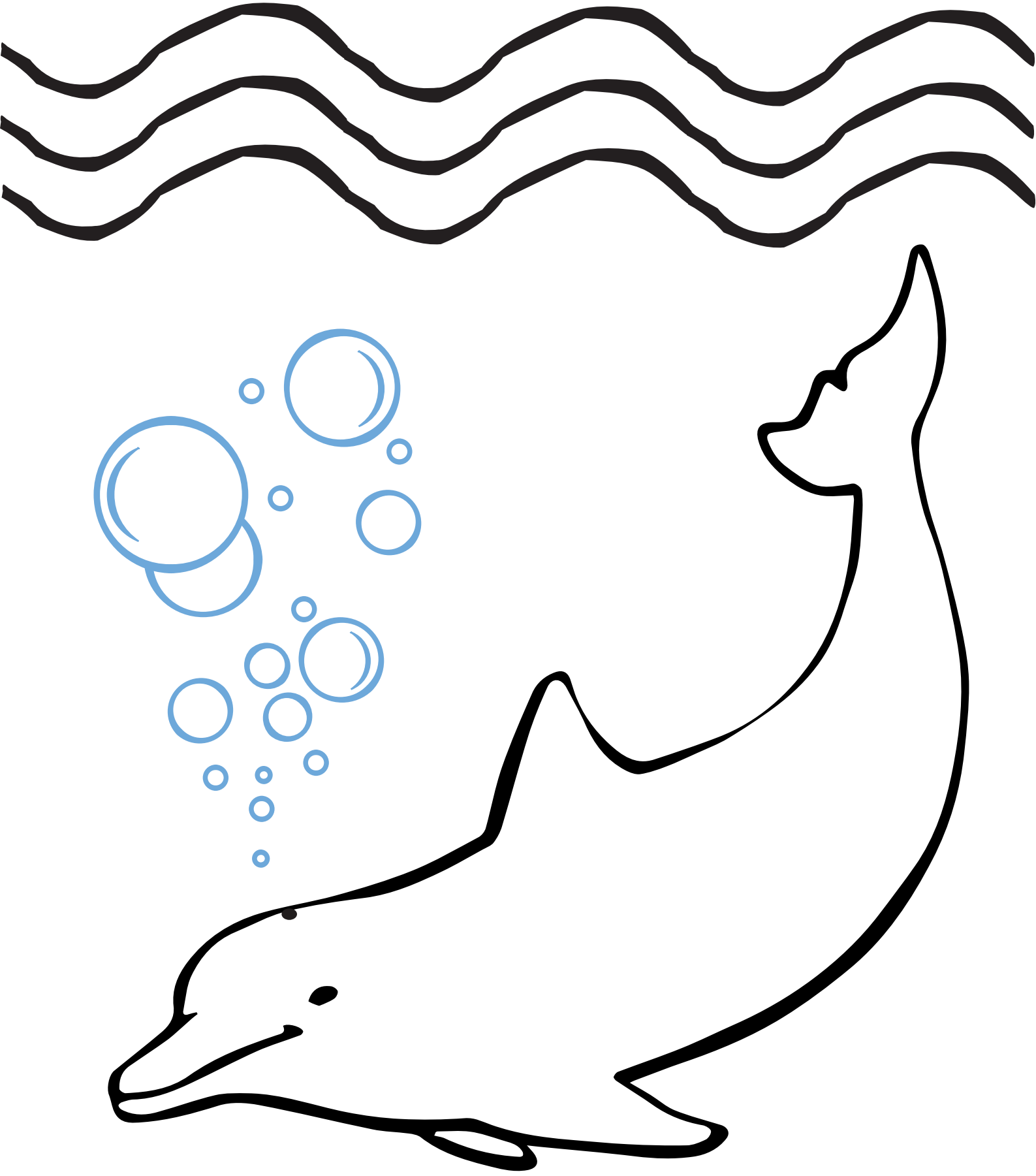

DOLPHIN

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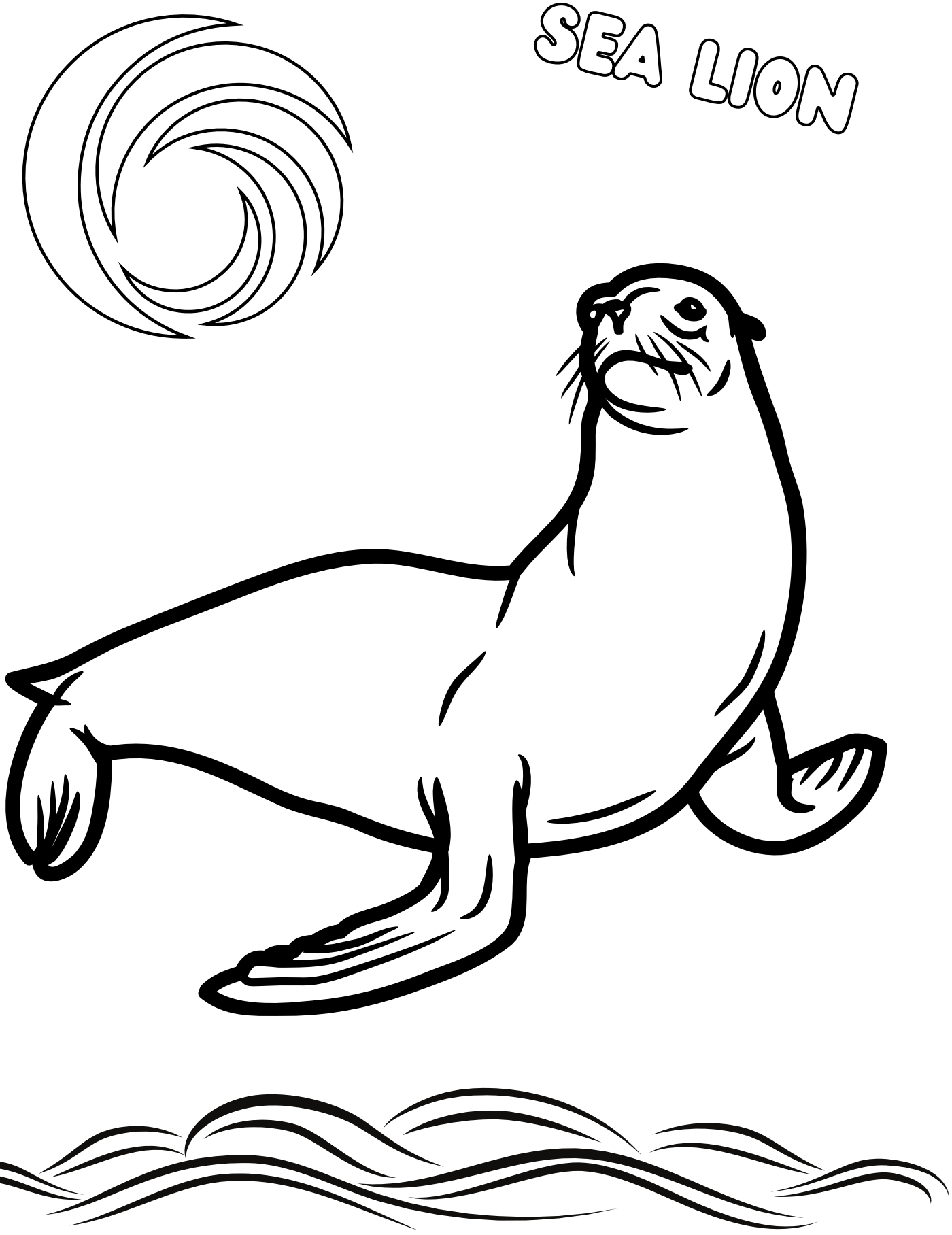
SEA LION



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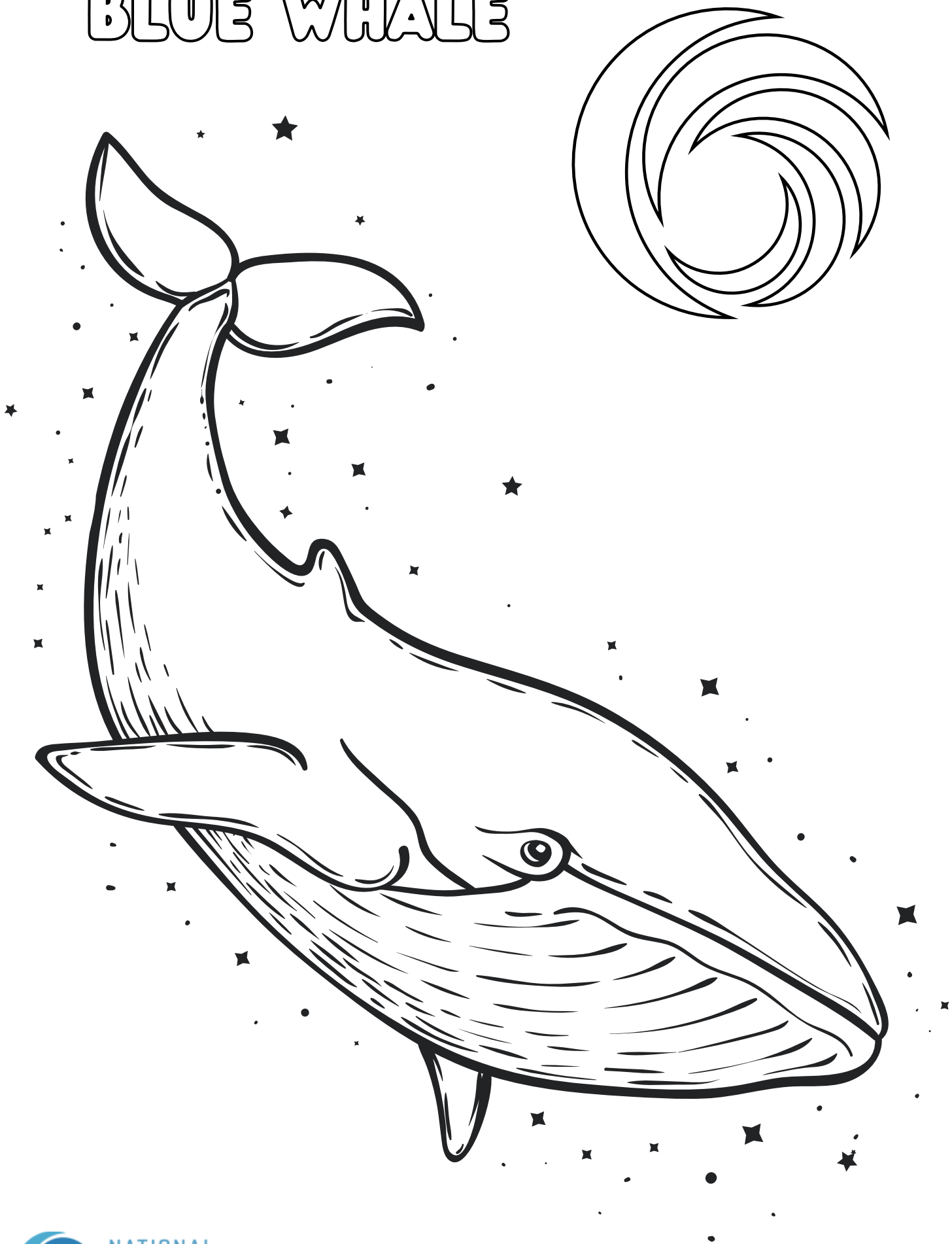
BLUE WHALE



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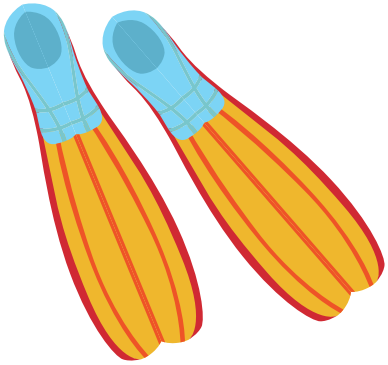
SWIMMING

When humans SCUBA dive or snorkel, they wear _____ on their feet that mimic marine mammal _____ so they can move faster through the water while using less energy.



Human divers can move both legs together like a dolphin, called a _____ kick.

They can also kick using one leg at a time, called a _____ kick.

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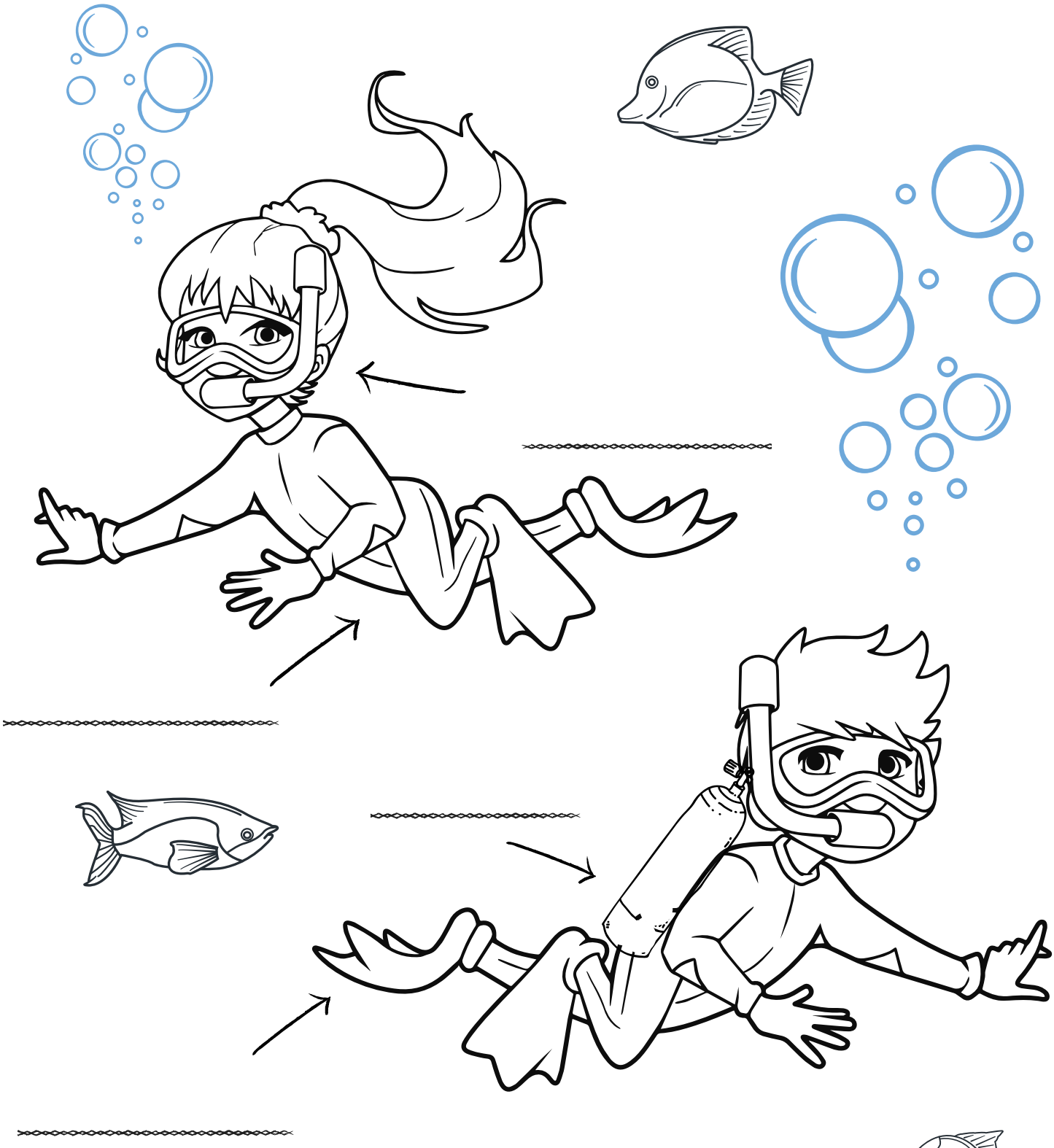
WHAT EQUIPMENT DO HUMANS NEED TO STAY UNDERWATER?



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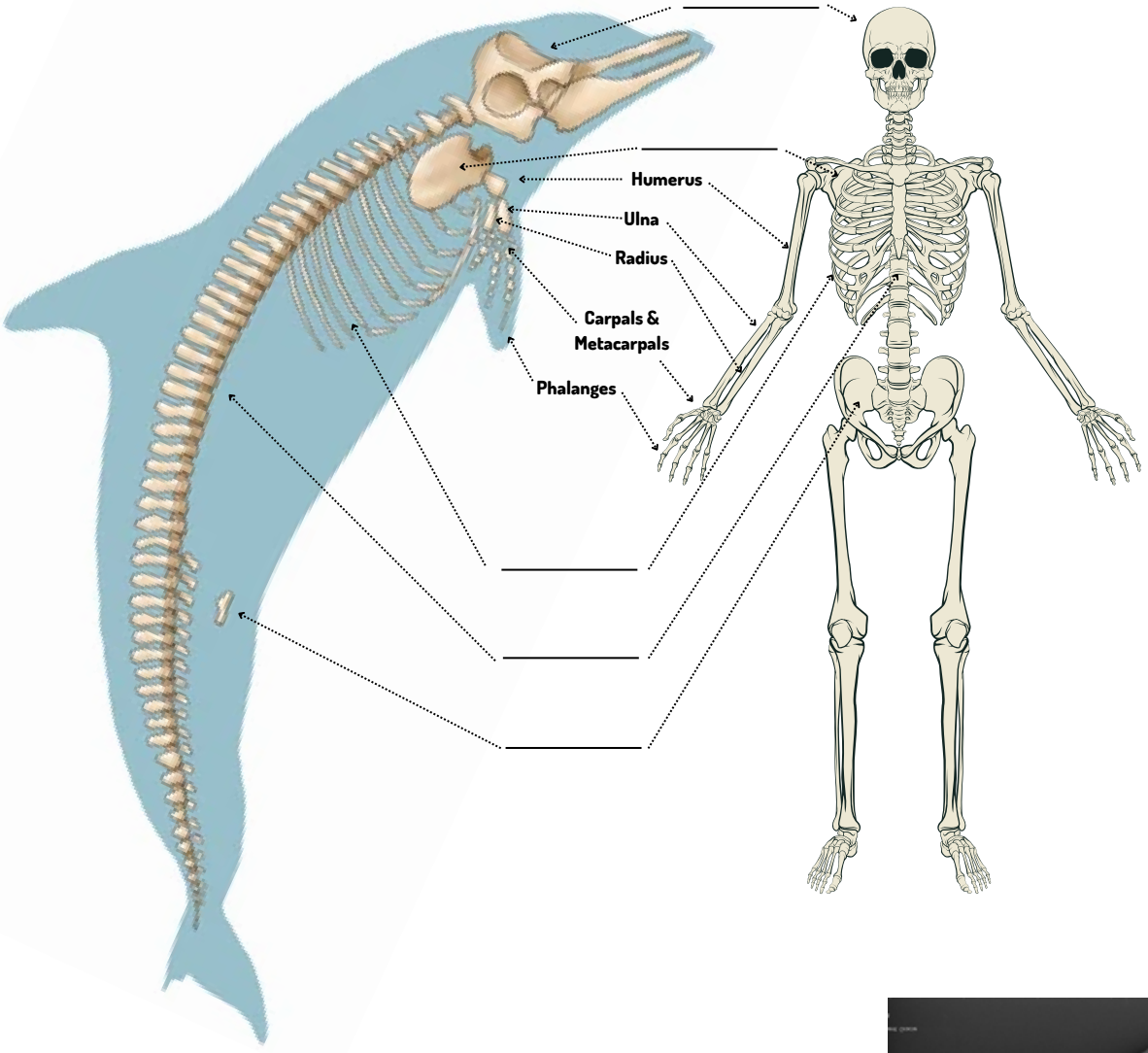
HOMOLOGOUS STRUCTURES

Homologous structures are similar physical features in organisms that share a common ancestor, but the features serve different functions. An example of homologous structures are the limbs of humans and dolphins.



scapula

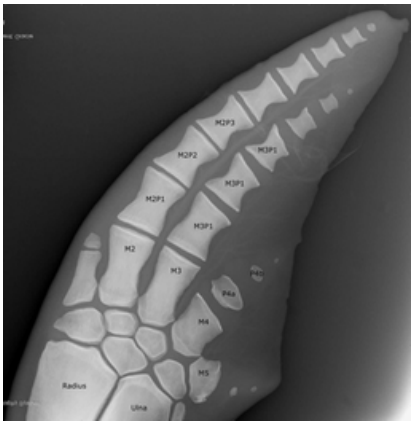
spine

ribs

pelvis

skull

This is a real dolphin radiograph, also called an x-ray, of a pectoral fin. NMMF scientists can use images like this to figure out the age of a dolphin and if it is healthy.



Barratclough, A., Sanz-Requena, R., Marti-Bonmati, L., Schmitt, T. L., Jensen, E., & García-Párraga, D. (2019). Radiographic assessment of pectoral flipper bone maturation in bottlenose dolphins (Tursiops truncatus), as a novel technique to accurately estimate chronological age. Plos one, 14(9), e0222722.

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MAMMALIAN DIVE RESPONSE

The mammalian dive response is a set of physiological changes to diving in water and is found in all air-breathing vertebrates studied to date. Draw a line from each response below to the part of the body it affects.

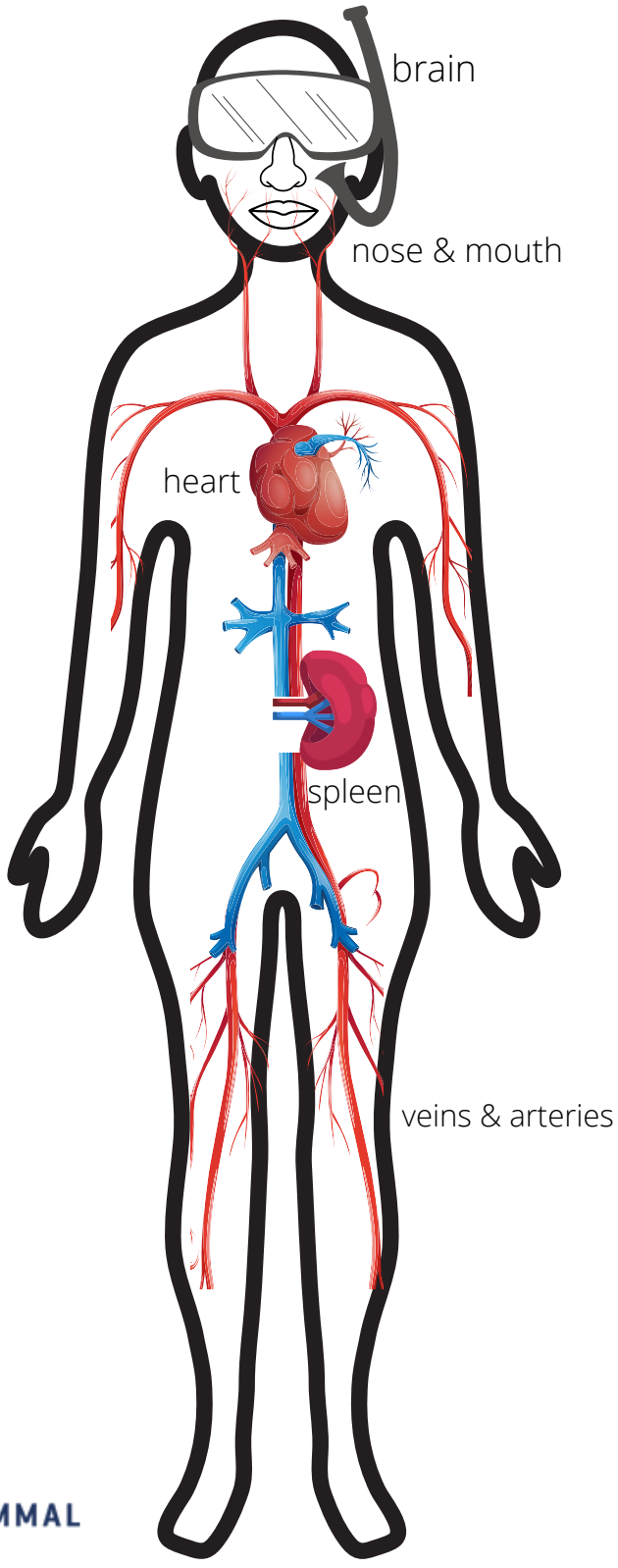
Contracts (squeezes) to pump out extra red blood cells which carry oxygen

Blood flow is reduced in these blood vessels, called vasoconstriction

This part of the body triggers the dive response when immersed in cold water

Rate slows down and becomes irregular (bradycardia & arrhythmia)

Oxygen stores are directed to the these body parts, enabling submersion for an extended time



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THERMAL ADAPTATIONS

Since humans do not have the layer of fat that marine mammals have called _____, divers wear a _____ around their body to create a warm layer that protects them from the cold water.

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CHALLENGES IN THE DEEP

As you go deeper in the ocean, the pressure is equal to 1 atmosphere of air for every 10 meters (33 ft) under water.

Feet

11

22

33

44

55

66

77

88

99

110

121

132

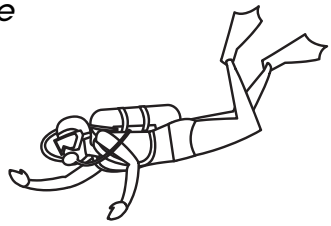
143

154

1 *atmosphere of pressure at the ocean surface*

2 *atmospheres of pressure*

3 *atmospheres of pressure*



4 *atmospheres of pressure*

5 *atmospheres of pressure*

Light dissipates quickly in coastal waters...

Colors with lower energy, such as reds, oranges, and yellows are filtered out quickly.

Blue and violet light waves have shorter wave lengths & more energy, so they travel deeper through water.

... but **sound** travels 4 times faster, and much farther, in water than in air at any depth! No wonder marine mammals use **sound** to hunt, navigate and communicate!

ECHOLOCATION

Echolocation, also called biosonar, is a biological sonar used by several animal species. Echolocating animals project sound into the environment and listen to the echoes that return from various objects the sound encounters. They use these echoes to locate and identify the objects. Echolocation is used for navigation, foraging, and hunting in various environments.

BATS

DOLPHINS

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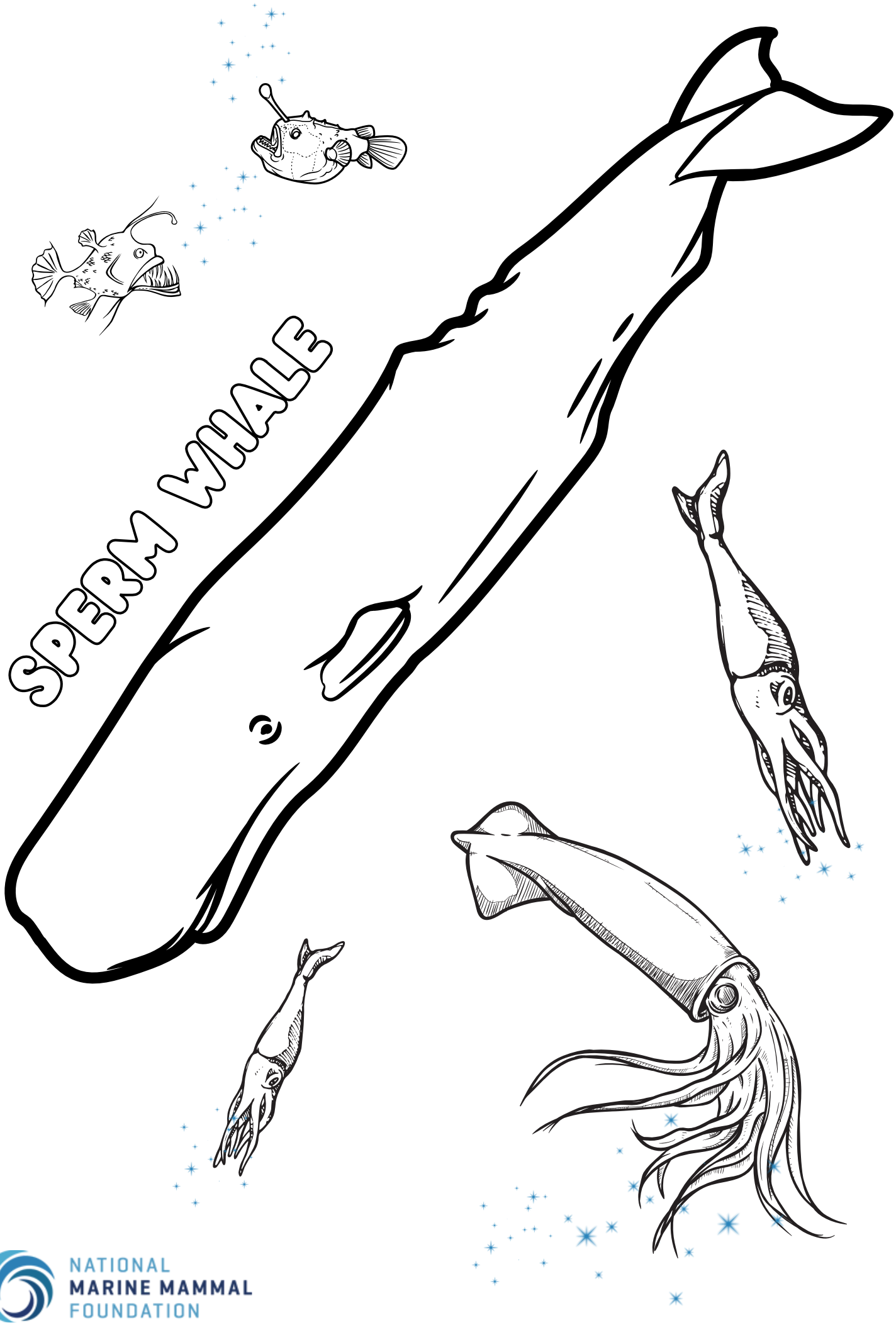

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SEALS

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Let's Explore the Diving Physiology of Marine Mammals!

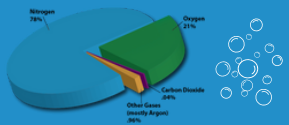
UNDERWATER CHALLENGE

1. Movement

2. Pressure & Buoyancy

Air compresses as we go down, and our buoyancy also decreases.
Air pockets in our bodies can rupture as we go up.

3. Gasses

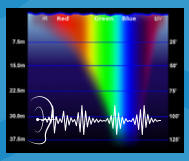


Oxygen is limited on a single breath hold and must be conserved.
We absorb more nitrogen as we dive deeper.
More nitrogen = impaired nervous system
Humans have a low tolderance to carbon dioxide build-up.

4. Heat

Water conducts heat away from the body 25x faster than air.
Even in warm water, we lose heat quickly.

5. Light & Sound



Water is about 800x denser than air.
Light slows and refracts underwater.
Blue light goes the deepest.
Sound travels 4x faster and
much greater distances in water!

ADAPTATIONS

1. Anatomical Adaptations

1. Hydrodynamics: Body shape creates minimal drag
2. Fins and flippers!

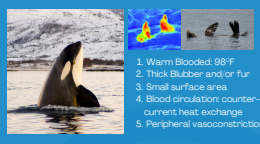
2. Lungs

1. 1st dolphin selfie!
2. 90% lung exchange
3. Collapsible lungs and flexible rib cage (allowing for thoracic collapse) protects from taking up excessive nitrogen and prevents the bends

3. Blood & Blood Flow

1. High oxygen retention (↑ blood volume, ↑ red blood cell count, ↑ hemoglobin, ↑ myoglobin), large or extra spleens
2. Mammalian Dive Response conserves oxygen
3. Peripheral vasoconstriction limits uptake of nitrogen by moving blood to the core of the body and away from fat tissue in the blubber (lipids absorb nitrogen at a higher rate than other tissues)
4. High tolerance to carbon dioxide and lactic acid build-up

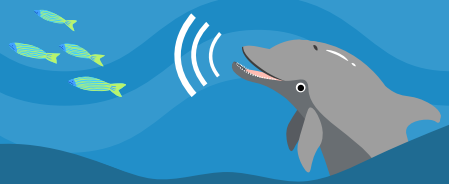
4. Thermoregulation



1. Warm Blooded: 98°F
2. Thick Blubber and/or fur
3. Small surface area
4. Blood circulation: counter-current heat exchange
5. Peripheral vasoconstriction

5. Senses: Seeing & Hearing

1. Excellent eyesight underwater and above water
2. Sensitive underwater directional hearing
3. Echolocation



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